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TESTING RADIO SETS

TESTING RADIO SETS

By

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PREFACE

TO FIFTH EDITION

THERE has been a striking change in radio technique in the twenty years since this book was first written. The testing of receivers is now a highly specialised business, usually carried out in well equipped workshops. Even the individual service-man who locates and possibly rectifies troubles on the spot, has, to-day, to be equipped with a variety of instruments such as Signal Generators and Output Meters if he is to operate efficiently.

The distinction between the service-room and the designs laboratory becomes increasingly difficult to define, while the continually changing fashions in radio receivers make detailed descriptions of particular types impracticable.

I have therefore endeavoured to present the fundamental principles of set testing, including a certain amount of design information to assist the reader's understanding and so help him in the exercise of deductive reasoning which is the basis of servicing.

J. H. REYNER

BOREHAM WOOD
June 1949

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CHAPTER I

INTRODUCTION

FAULT location is one of the most important factors in the design, testing and maintenance of a radio receiver. Without proper method it is also one of the most difficult, but if tackled in the right manner it need have no terrors, even for the uninitiated. The process is one of highly trained inductive reasoning, for the most one can do is to follow the laws of cause and effect. The properly constituted radio set receives energy on the aerial, amplifies it, alters the form of the energy and finally converts it into sound, the volume, fidelity and general character of which must conform to certain expectations. If this is not the case we have to find which particular link in the whole complex chain is not functioning at its correct efficiency.

The only way in which we can do this is by the employment of a system. If one is walking down a path in the dark and finds one's progress suddenly impeded, one instinctively puts out a hand to find the obstacle. According to the nature of the impedance —whether one has stubbed a toe, barked the shins or stopped a dastardly blow amidships, so one automatically looks for the obstacle in the appropriate region.

This is a natural exercise of the faculty of inductive reasoning. The brain automatically and instantaneously locates the point which has ceased to function correctly and sends the hand as a messenger to discover the cause. We have to use the same procedure in testing electrical machinery, for, except in very specialised cases, we are not able to see what is happening and we have to determine the cause of the trouble by finding whether each individual portion of the receiver reacts as it should do.

We are concerned in this book with the methods by which the reasoning is best applied together with a discussion of the specialised testing equipment which has been evolved as the result of experience to facilitate the operations.

General Testing Methods. By way of introduction we shall discuss in broad terms the general technique of testing and then proceed to a more detailed analysis in later chapters. Many simple faults in receivers are shown up by a check on the currents or voltages in the circuit.

Voltage measurements are easier to make, though they require a little more thought in their interpretation. We shall, therefore, consider these first. In any receiver there is a source of high tension supply from which all the various valves are fed, and the procedure adopted is to check first of all the voltage across the supply and then subsequently the voltages at progressive points in each of the individual circuits. Fig. 1.1 represents a part of a battery receiver which may be used for purposes of illustration.

Measure first the voltage across the h.t. terminals on the set. The voltage on an h.t. battery is not constant but falls with the life of the battery in the manner shown in Fig. 1.2. When the battery is new the voltage is equal to, or may even slightly exceed, the rated value. It very quickly falls to a more steady figure after which it tails off gradually until, towards the end of the useful life, a rapid falling off sets in. When the battery reaches this point it is of little use, largely because the internal resistance of the battery rises very sharply as indicated on Fig. 1.2 and, as is discussed later, this gives rise to numerous troubles such as bad quality or instability.

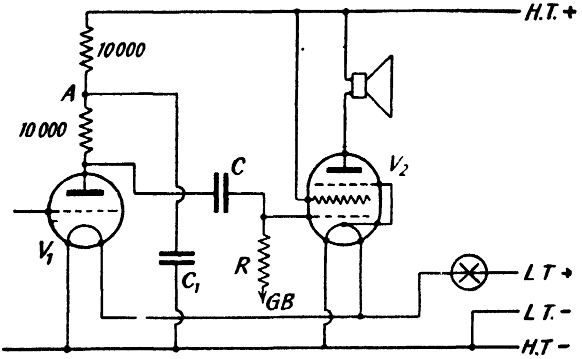


Fig. 1.1. Low-frequency portion of Battery Receiver Circuit.

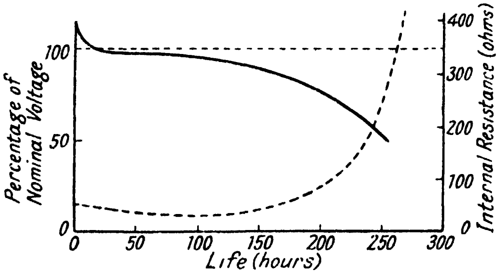


Fig. 1.2. Variation of Voltage and Internal Resistance of Typical H.T. Battery.

Step-by-step Testing. Assuming that the battery voltage is satisfactory, however, the positive voltmeter lead may be moved progressively down the circuit, leaving the negative lead still connected to the negative h.t. line. Taking the output valve first, one would measure the voltage on the anode of the output valve. Since the anode circuit only contains the loud speaker, the volts on the anode should not be much less than full amount. The extent of the drop can easily be estimated from a knowledge of the loud speaker resistance and the anode current of the last valve.

The type of loud speaker commonly used to-day is the moving coil type having a low resistance speech coil with a matching transformer. It is the primary of this transformer which is actually in the anode circuit and this will have a resistance of the order of 500 ohms. If the output valve is taking 20 milliamps this will drop 10 volts,[1] so that the voltage on the valve anode should be roughly 10 volts less than the full amount.

If no voltage appears on the anode of the valve, the transformer is disconnected. On the other hand, if the voltage on the anode is the same as the full amount so that there is no voltage drop on the transformer, it indicates that the output valve is not passing any current.

Various possibilities would account for this. The valve itself may be defective, which may be proved either by checking the valve itself or by replacing the valve with a similar type. Alternatively, the filament voltage may be much too low or the filament circuit may be broken. Thirdly, the valve may be heavily over-biased, due to some incorrect connection earlier in the circuit, or fourthly, the connections in the valve holder may be defective, so that although the circuit is apparently connected to the valve it is not actually reaching the valve pins.

A similar procedure would be adopted on the preceding valve where there are two points at which the voltage may be checked. One of these is at the end of the decoupling resistance, and the second is on the anode of the valve itself. Once again, if the valve is functioning correctly, the voltage at these two points will be progressively less than the full amount. No voltage indicates a break in the circuit, full voltage indicates no current flow.

Allowance for Meter Consumption. A point to be noted here, however, is that the meter itself will take current, and although this is small it will cause an appreciable voltage drop on the relatively high resistance in use. If the detector valve is taking 4 mA, and the h.t. voltage is 120 the voltage at the point A should be 80 volts, the 4 mA passing through the 10,000 ohm resistance being responsible for a drop of 40 volts. If we use a 5 milliamp meter giving a full scale reading with 120 volts, the actual reading will be in the neighbourhood of 55 volts, for at this reading the meter itself is passing about 2½ mA which, in addition to the 4 mA taken by the valve, will cause a voltage drop on the 10,000 ohm resistance of 65 volts.

Conditions are even worse when one endeavours to measure the voltage actually on the anode of the valve; in fact, for a resistance-coupled circuit of this sort it is almost essential to use a meter requiring not more than 1 mA for full scale deflection. With such a meter the error, though still present, will be very much less and a satisfactory indication can be obtained. The circuit of Fig. 1.1 for example should, if operating properly, give 40 volts on the anode of the detector valve assuming a 4 mA anode current. If we measure this with a meter which takes only 1 mA full scale, the current consumption of the meter at 40 volts will only be 0.33 mA, causing the actual reading to be about 33 instead of 40—not a serious error.

---

[1] It is convenient to remember that a resistance of 1000 ohms drops 1 volt per milliamp. Hence the voltage drop on any resistor is obtained by multiplying the resistance in thousands of ohms by the current in milliamps.

On the other hand, there are many circuits in which the anode resistance is very much higher than the value shown and in which the anode current of the valve is proportionately smaller. In such circumstances even a low consumption voltmeter is liable to give misleading results. An alternative method of attack is to measure the voltage across the various resistors. Provided the effective resistance of the meter is two or three times higher than the resistance being measured, this method will give a fairly reliable indication. For example, we have just seen that the voltage drop across the two 10,000 ohm resistances should be approximately 40 volts each in the example just considered. A 5 mA meter reading read 120 volts full scale would have an internal resistance of 25,000 ohms, and this connected across 10,000 ohms would give an indication of the order of 30 volts—again not accurate, but sufficient to indicate whether there was any voltage drop at all, which is the primary object of the test.[1]

In cases where the resistance in question is of the same order as, or even higher than, the meter resistance, even this method is unsatisfactory and the only solution is to note the current through the circuit and calculate the voltage drop required by multiplying the resistance by the current.

Mains-operated Receivers. Now let us consider the circuit of Fig. 1.3. Here is a mains-operated receiver having the customary self-bias in each valve, and also showing an h.f. stage employing screen grid valve. The first test would be, as before, to check the h.t. voltage on the line. This will normally be between 250 and 350 volts. If it should be found to be seriously different from the expected value, the power unit must be examined in accordance with the tests quoted in Chapter VIII on Mains Apparatus. Owing to the fact that the voltage from a mains-operated power unit is usually dependent to quite a large extent upon the actual current being taken, this test at once gives some indication of the performance of the circuit. If the voltage is low it indicates either some defect in the mains supply unit (possibly a defective rectifier valve), or it indicates a very heavy load across the h.t. line, such that the voltage is being reduced by an unusually large voltage drop in the power supply circuit. Conversely, a high voltage indicates that the load is too low and there may, in fact, be a complete break in some portion of the circuit or circuits across the h.t. line, in consequence of which the overall voltage will rise.

---

[1] The 25,000 ohm meter in parallel with the 10,000 ohm resistance have an equivalent resistance of (25,000 × 10,000)/(25,000 + 10,000) = 7,150 ohms. If we assume that the anode current is not appreciably changed by this modification, the voltage drop across this part of the circuit will be 28·6 volts, and this is what the meter will indicate. Actually the current will probably increase slightly, so that an exact calculation is not practicable.

Assuming that the line voltage is satisfactory, tests would be made on the various valves in the manner already described. It must be remembered, however, that the voltage between a point and h.t. – may not be the true voltage required, because the valve may include in its cathode circuit a bias resistor, and the anode current flowing through this resistance develops the voltage necessary for the grid bias. Allowance must be made for this in interpreting the result.

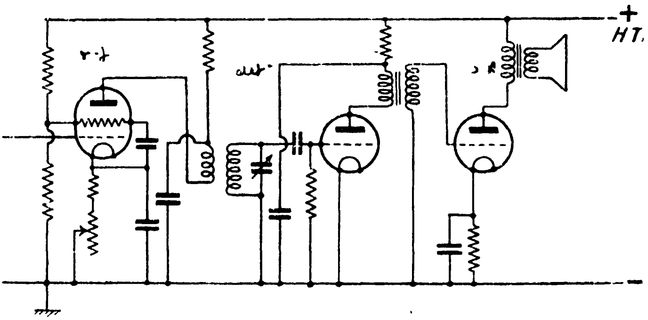


Fig. 1.3. Part of Typical Mains Receiver Circuit.

The output circuit grid bias, for example, may be quite small —about 10 volts or so—or in the case of power triode it may be 50–100 volts. The voltage on the valve itself, therefore, should be measured, if it is desired to be known accurately, between the anode and the cathode of the valve and not h.t.–. Similarly in the h.f. valve, which is of the vari-mu type, a bias of as much as 40–50 volts may be developed in the minimum volume setting, as the volume control is obtained by increasing the bias on this valve from its normal value of 1½ to 2 volts up to anything from 20–50 volts, depending on the type of valve.

With this reservation the method of testing is exactly the same as already laid down for the Fig. 1.1 circuit. There is an additional test to be made on the screen voltage of the h.f. valve. This voltage is obtained from a potentiometer tapped across the full h.t. supply, and the voltage at the tapping point may be measured with a voltmeter in the usual way. The component resistances of this potentiometer will, in general, be of the order of 20,000 to 30,000 ohms, so that a high resistance voltmeter is again desirable if a reasonably accurate indication is required. In fact, with mains apparatus, owing to the dependence of the voltage on the current taken, it is more than ever desirable to use a high resistance meter so that the current taken by the meter itself is only a small proportion of the total current and does not invalidate the reading.

In a.c. receivers there are other voltage measurements which may have to be made, such as the voltage on the secondary of the h.t. transformer. For this measurement an a.c. voltmeter must be used, but as the normal test meter of to-day is designed for both d.c. and a.c. measurements, this only involves altering the setting of the instrument. Generally speaking, the voltage across each half of a double wave transformer is of the same order as the h.t. voltage, so that with a set delivering 400 volts h.t. a 500 volt a.c. meter should be used to read the voltage across each half. A further point requiring checking is the filament or heater voltage, for which purpose the low range of the instrument would be required. This voltage should be measured at the heaters of the valves themselves, for owing to the fairly large current taken it is possible to lose quite an appreciable fraction of a volt in the leads from the transformer to the heaters.

A further point is the rectifier valve heater which again is usually 4 or 6·3 volts in a modern receiver. In measuring this voltage it should be remembered that although the voltage itself is small, the rectifier filament is usually several hundred volts above earth in potential, so that care must be taken not to allow one of the connecting wires on the meter to touch any other part of the circuit. It is desirable, when testing mains receivers, to use insulated spikes, known as "test prods" on the end of the meter leads.

Current Tests. In addition to checking the voltages at various points it is sometimes helpful to measure the current. The anode current of any suspected valve may be tested by inserting a milliammeter in the anode circuit. This, of course, involves breaking into the circuit in some way. The modern receiver is so complex and compact that the only practicable way of achieving this is to break the circuit at the appropriate point by unsoldering the connections. This must be done with due consideration, so that the addition of the meter leads into the circuit will not introduce trouble. The meter should be introduced at a point of zero signal potential, e.g. at the h.t. end of an anode circuit or at the earthy end of a cathode circuit.

In the modern receiver the circuiting is almost invariably designed to keep signal currents out of the supply lines by suitable decoupling. Hence it is usually easy to find a point at which a circuit may safely be broken to check the valve anode current.

The connection of the meter at any other point is liable to cause trouble because of the possibility of stray coupling from one circuit to another through the proximity of the meter leads to a previous part of the circuit. This may cause the valve under examination to develop a continuous (possibly inaudible) oscillation and under such conditions its anode current will be quite different from the normal.

Particularly if the oscillation is strong, the anode current may rise to a value several times the usual figure, or, on the other hand, if the circuit contains a condenser and leak so that rectification can take place, the valve may bias itself back to such an extent that the anode current drops back almost to zero.

The anode current of the valve should be known approximately from the characteristics published by the makers, and it is easy to check any suspected valve or, if necessary, each valve in turn. If the anode current is found to be abnormal then either the valve is faulty or the circuit constants are incorrect in some particular. We shall discuss the various possibilities in later chapters.

Voltage Drop Method. Alternatively the anode current may be deduced by measuring the voltage drop across a resistance in the circuit.

Almost invariably the circuit will itself contain such a resistance, so that no disturbance of the conditions is involved. For instance, in Fig. 1.1 the anode current of V_1 can be determined by noting the voltage drop across either of the 10,000 ohm resistors. The current is then obtained by dividing the voltage by the resistance, and if the resistance is expressed in kilohms,[1] the current is given directly in mA.

Again in Fig. 1.3 the current in the output valve may be checked by noting the drop across the cathode resistor, which voltage should incidentally be the correct operating bias for the particular valve. This method is convenient and accurate provided the meter resistance is high compared with the resistor across which it is connected.

Colour Code. The reader should be familiar with the standard colour code now almost universally adopted for resistors. In this code the resistor is painted a colour dependent on the first figure of its resistance, while one end is painted with a second colour indicating the second figure. The number of noughts is then determined by a third colour in the form of a dot or ring in the middle.

Thus a 35 ohm resistance will be painted the same as a 35,000 ohm resistance, both having an orange body and a green tip, but one will have a black ring and the other an orange ring.

The code is easily memorised and is as follows:

TABLE I—RMA COLOUR CODE

Body	1st digit	Tip	2nd digit	Dot or Ring	Remaining digits
Black	0	Black	0	Black	—
Brown	1	Brown	1	Brown	0
Red	2	Red	2	Red	00
Orange	3	Orange	3	Orange	000
Yellow	4	Yellow	4	Yellow	0,000
Green	5	Green	5	Green	00,000
Blue	6	Blue	6	Blue	000,000
Violet	7	Violet	7		
Grey	8	Grey	8		
White	9	White	9		

---

[1] One kilohm = 1000 ohms.

A fourth ring is often to be found coloured gold or silver. This is to indicate the *tolerance*. It is not practicable to produce, in quantity, resistors (or other components) having exactly the value specified. The manufacturers therefore grade their products as being within a certain percentage of the rated value. If a resistor has to be replaced, therefore, the new resistor should be within the same tolerance as the old.

The tolerance code is as follows:

± 5 % gold tip or ring
± 10 % silver tip or ring
± 20 % no additional colour.

As part of the grading scheme now adopted by manufacturers, resistors are now only available in certain values at intervals of approximately twice the tolerance. This has considerably simplified the manufacture and has caused no undue difficulty in design.

The basic values are as shown below. These values may all be multiplied by any multiple of 10 (up to a maximum of 10 megohms) i.e. in the 20% range one can obtain 15,150, 1500, 15,000, 150,000 ohms and 1·5 megohms.

20 % *Tolerance:* 10, 15, 22, 33, 47, 68.

10 % *Tolerance:* 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, 82.

5 % *Tolerance:* 10, 11, 12, 13, 15, 16, 18, 20, 22, 24, 27, 30, 33, 36, 39, 43, 47, 51, 56, 62, 68, 75, 82, 91.

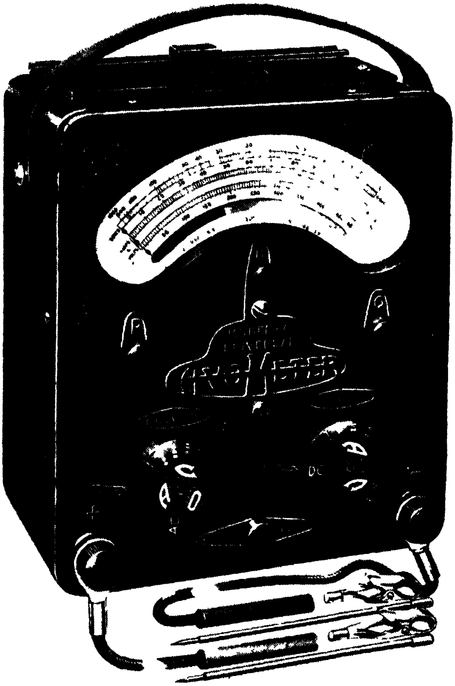
Location of Faulty Section. It is not necessary, of course, to check every voltage and current in the faulty set. There is usually some indication as to the portion of the set which is not functioning. If such indication is not immediately evident, it is not very difficult to narrow down the field.

The experienced service-man will often be able to do this without the aid of auxiliary apparatus, but the operations are simplified if functional tests can be made, for which purpose the testing laboratory of to-day is provided with equipment enabling the performance of the receiver to be checked either as a complete whole or in part.

Signal Generators. The first of these items of equipment is the signal generator, which is an arrangement for producing an artificial signal of known characteristics. It consists of an oscillator capable of being tuned to the frequency required and therefore usually containing a series of different ranges selected by means of a switch. The radio frequency oscillation is modulated with a fixed note to an extent which may either be fixed or variable depending upon the type of instrument. Finally, the output is fed through an *attenuator*, by means of which it may be varied from a maximum of the order of a volt down to a few microvolts so that it can imitate either strong or weak signals at will.

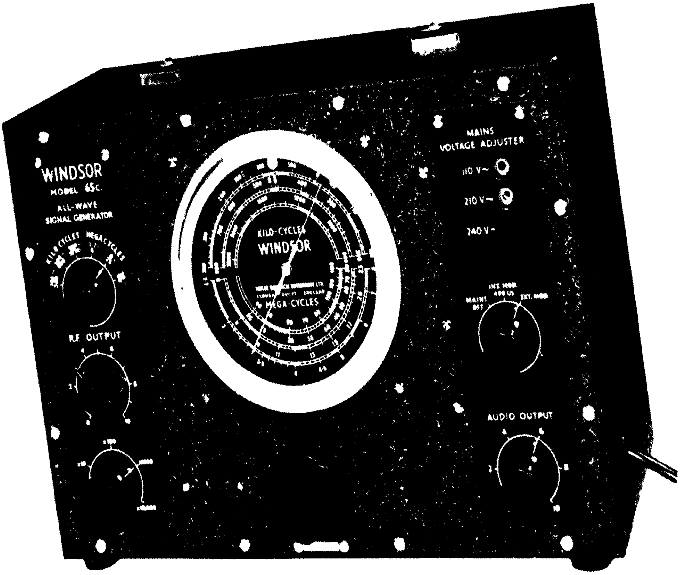
We shall discuss signal generators in more detail in Chapter III. For the present it is sufficient to note that with such a device it is possible to introduce a signal of known strength at any point in the

PLATE I



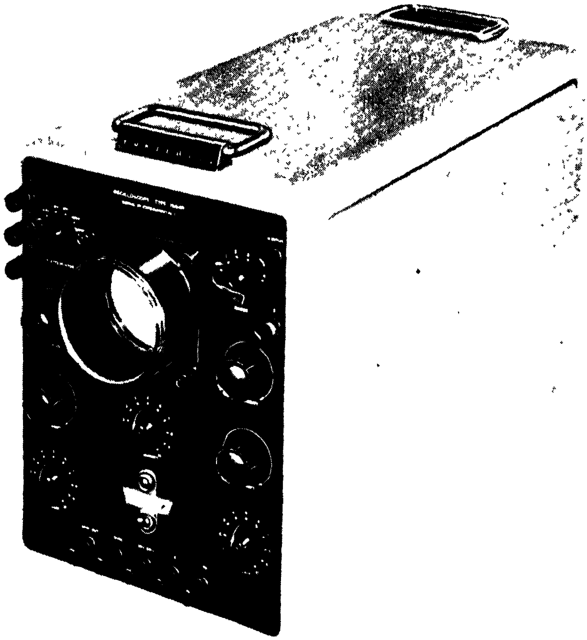
A typical service test meter is the Avometer illustrated here. It reads voltage and current, both a.c. and d.c., and resistance. Note the test prods for obtaining safe access to live parts of the circuit.

PLATE II



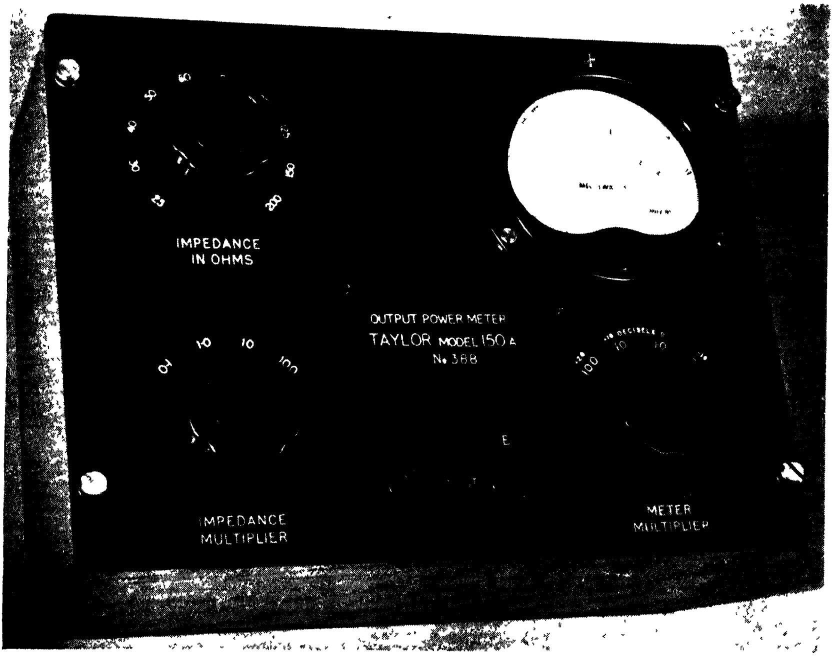
The Taylor Signal generator illustrated here is a typical service instrument covering r.f and i.f ranges, with a built-in attenuator and provision for both internal and external modulation.

PLATE III



This Furzehill Oscilloscope is a de luxe instrument. It has d.c. coupled amplifiers on both axes, which give a good pattern with signals of less than one millivolt. It is suitable for both audio and radio frequencies.

PLATE IV



The Taylor Output Meter shown here provides an artificial load of impedance ranging from 2·5 to 20,000 ohms and measures the power developed.

receiver and to observe the result. This may be checked aurally by noting the sound produced in the loud speaker or, more scientifically, by using some form of output meter which measures the a.c. voltage developed across the loud speaker, or across an artificial load which is substituted for the loud speaker.

Under these conditions the theoretical performance can be arrived at very simply from a knowledge of the characteristics of the valves used, and it is therefore a simple matter to estimate how much input would be required at various points in the receiver to produce the required output.

Testing Procedure. For example, referring again to Fig. 1.3., we should be able to inject voltage into the grid circuit of the detector valve, at which point we should expect a voltage of the order of one volt r.f. to produce us a substantial signal in the loud speaker. Failure to do this indicates that something is wrong either with the detector, or the output valve, or the coupling between them.

If we find that our expectations are fulfilled at this point, however, we move the input back to the grid of the preceding valve where we should expect the input necessary to be about 100 times less, the actual gain of the stage depending upon the type of set with which we are dealing. If this is not found to be the case then there is a defect in the r.f. stage or in the coupling between it and the detector.

By similar procedure we can ultimately arrive at the aerial of the set itself, rectifying any faults as we proceed, until the whole instrument is operating at its full efficiency. The accuracy and complexity of the tests made at each stage depend entirely upon the work in hand, i.e. whether we are merely concerned with rectifying a fault or require design information.

Audio Oscillators. When dealing with audio-frequency amplifiers it is desirable to have a similar arrangement for generating audio frequencies. This is called an a.f. oscillator and is usually of the beat-frequency type, although R-C oscillators are also used. The main requirements are that it shall be able to generate a signal over the whole audio-frequency range from about 25 c/s up to 10,000 or 15,000 c/s. It is also important that the waveform of the output shall be pure and free from harmonics. This point is not of great importance with a signal generator because the results obtained are not greatly dependent on waveform (provided this is reasonably good) but the audio-frequency oscillator is often used in locating sources of distortion for which it is essential that the oscillator itself shall be free from distortion, so that any distortion which is obtained in the output of the amplifier can be credited to the amplifier itself.

Valve Voltmeters. For measuring the signal voltage at various parts of the circuit the ordinary test meter is useless. Audio-frequency signals can sometimes be estimated by using the a.c. range of a test meter, but this usage is limited; for radio-frequency measurements a special type of meter is essential. The most suitable instrument for both purposes is the valve voltmeter, which consists, in essence, of a valve so used that a signal applied to its grid will cause a change of anode current. Within limits, this indication is independent of the frequency of the signal so that the instrument can be used for r.f. or a.f. tests, while the valve can be so circuited as to have a very high input impedance so that the circuit under test is not appreciably affected by the connection of the voltmeter across the points at which the measurement is being made.

The anode current change is recorded on a normal d.c. meter, calibrated in terms of the a.c. input signal applied to the grid of the valve. Further details of valve voltmeters will be found in Chap. III.

Cathode Ray Oscilloscopes. Finally, there is the cathode ray tube, a device which is of the greatest value in testing technique because it enables us to see the waveforms of the currents and voltages with which we are dealing. In making tests for distortion, for example, considerable time is saved by being able to examine the waveform of the output, while many other functions such as detection, modulation, frequency changing, etc., can be examined more easily and in greater detail if the actual form of the signal can be seen.

The cathode ray oscillograph, in fact, saves time not only in audio-frequency testing but also throughout the whole of the receiver. A special chapter has therefore been devoted to a discussion on this device and the methods obtaining the best use from it.

This brief review indicates the general method of attack on the problem of set testing. In succeeding chapters we shall consider equipment and the methods in more detail.

CHAPTER II

METERS

HAVING discussed very briefly the general methods to be followed, it will be as well to consider the equipment necessary. The first essentials are a voltmeter and a milliammeter. These instruments should be of the moving-coil type, consisting of a small coil with a pointer attached, pivoted in a strong magnetic field. The passage of current through the meter causes the coil to rotate, and the extent of the movement gives a measure of the current.

With a moving-coil meter the direction of movement of the pointer depends on the direction of the current flow through the instrument. The terminals are therefore always marked to distinguish positive and negative. (But a meter having + or – on its terminals is not necessarily a moving-coil meter.)

The voltmeter should be capable of measuring voltages from one to at least 600 volts a.c. or d.c. The milliammeter should also have a number of ranges, for one requires to measure anode or screen currents of single valves taking as little as one or two milliamps or the total consumption of a set which may be 50 mA or more.

Large currents of the order of amperes do not require such frequent checking, though it is useful to be able to check filament or heater consumption. The best solution is to use a combination instrument which, by switching or similar means, can be used for all the foregoing measurements. Such instruments are made by various firms, some of the best known types being illustrated herewith.

Altering Meter Ranges. A combination instrument contains the necessary provision for altering the range as required. It is useful, however, to know how to adapt an existing meter for a different range. For a milliammeter this is done by connecting a resistance across the meter terminals as shown in Fig. 2.1. Then part of the current is diverted from the meter which therefore only reads a fraction of its former value.

If the shunt resistance is made equal to the meter resistance the current obviously divides equally and the meter reading is halved. In other words the scale has been doubled, for the current necessary to produce full scale deflection is now twice the original value. In general terms, if R is the meter resistance and S the shunt resistance the multiplying factor is $k=(R+S)/S$. The actual current will then be k times the indication given by the meter.

In many instances the meter resistance is not known. In such circumstances the shunt may be arrived at by trial. Set up the meter in a circuit to read full scale deflection. Then connect a shunt across the terminals and adjust the value till the reading on the meter is $1/k$ times the full scale value. The meter is then correctly shunted for a multiplying factor k, and all the readings on the scale should be multiplied by k. The test circuit should include a suitable resistance in series, because the connection of the shunt across the meter will alter its resistance and this may alter the actual current flowing. The inclusion of a "swamp" resistance in series obviates this difficulty provided it is large compared with the meter resistance. It should have a value such as to drop 20 volts or so with the current flowing.

A voltmeter is a milliammeter in series with a high resistance. Hence to alter the reading it is merely necessary to alter the value of series resistance. If the total resistance is R, then an additional resistance $(k-1)R$ must be added to make the meter read k times as much. Once again, this adjustment can be carried out, if necessary, by trial by connecting the meter across a suitable source of voltage and adding extra resistance until the reading is reduced to $1/k$ times the original value.

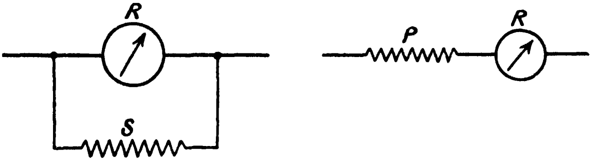


Fig. 2.1. Illustrating use of Shunt and Series Resistance for Altering Meter Readings.

Shunt resistances are of the order of a few ohms only. Series resistances are many thousands of ohms.

It should perhaps be emphasised that the voltmeter and milliammeter should not only be of the moving-coil type but must be thoroughly reliable. This is essential because a number of the tests which require to be made in practice depend upon the accurate determination of relatively small differences in the reading on the instrument, which must therefore be of first-class workmanship.

Figure of Merit. A final point is that the instrument must not consume too much current, for otherwise the current taken by the meter itself may cause quite incorrect indications, as was mentioned in the preceding chapter. Even with high grade meters there are occasions where this trouble arises.

The extent to which the power absorbed by the meter can be reduced is naturally determined by economic factors. The better the instrument the higher the price. A good meter will require 1 mA to produce a full scale deflection. If used as a voltmeter it will then require a series resistance of 1,000 ohms for every volt full scale deflection. Thus if we introduce a series resistance of 100,000 ohms, we shall obtain a full scale reading with 100 volts.

We say that such an instrument has a figure of merit of 1,000 (ohms per volt).

The figure of merit may easily be determined for any meter by ascertaining the current in milliamps required for full scale deflection. This figure should be divided into 1,000. It is not usually necessary in normal testing to exceed a value of 1,000 ohms per volt, though many meters use 5 mA movements corresponding to 200 ohms per volt. A lower value than this is not desirable as it limits the usefulness of the meter.

The need for a high figure of merit is not so great on low voltage ranges where the circuit current is many times greater than the meter current so that a figure as low as 50 ohms per volt is quite permissible here.

A.C. Meters. For mains apparatus, more particularly operating from alternating current supply, certain other equipment is desirable.

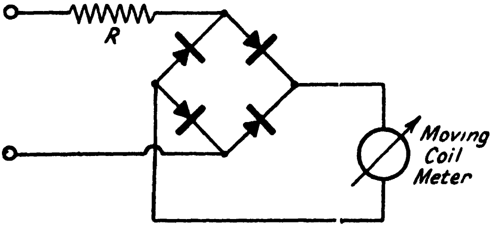


Fig. 2.2. Circuit diagram of A.C. Rectifier Meter.

An a.c. voltmeter capable of reading up to 500 and preferably 1,000 volts is useful for checking the supply voltage and the voltage on transformer secondaries. A second range on the instrument is also desirable, capable of reading up to about 10 volts. This is in order to check the voltage on the filament circuits of the various valves, which may range from 2 volts to 10 volts according to the type of valve.

A.C. meters are of various types, the most common being the moving-iron and the rectifier type. The former operates by virtue of the attraction of a piece of soft iron by the magnetic field set up by the current flowing through the meter. This attraction is independent of the direction of the current, so that the meter will read on alternating or direct current.

These meters, however, cannot be made so sensitive as the moving-coil variety, a figure of merit of 200 ohms per volt being quite good. Many meters are much worse than this, and the current required for full scale deflection should always be ascertained, to ensure that the meter itself will not absorb more current than the apparatus under test is meant to supply!

Rectifier instruments are d.c. moving-coil instruments incorporating a small metal bridge-rectifier as shown in Fig. 2.2. The a.c. is thus converted to unidirectional current, and this enables the sensitivity of the moving-coil type of meter to be utilised. Rectifier voltmeters can thus be made with a figure of merit of 1,000 ohms per volt or more if required. They are quite satisfactory for testing but will sometimes give misleading results in experimental work as the internal resistance changes with the current, while they are only accurate on a pure wave form, as explained later.

For high voltages (500 and upwards) electrostatic meters are convenient. These comprise a light vane pivoted between two fixed vanes like a skeleton variable condenser. The electrostatic force causes the moving plate to swing in between the fixed vanes and so to indicate the voltage. These meters are laboratory instruments, their main advantage being that they take a negligible current.

A.C. or high voltage meters should be provided with a pair of test prods, consisting of insulating rods terminating in a metal point. This enables one to place the metal ends on live portions of the circuit without any danger of shock from personal contact with possible high voltages in the receiver. This precaution is very necessary, and even with the prods in use the greatest care should be taken in making any test on the receiver while it is alive.

Ohmmeters. On many occasions a simple method of estimating the resistance of a circuit is of use. As is described in Chapter XI, a check on the resistance of any portion of the circuit may be obtained by the application of Ohm's Law, but an instrument which gives the actual resistance at a glance will often save time.

The simplest form of ohmmeter comprises a milliammeter and battery built into a suitable case whilst two terminals are provided for the connection of the external resistance to be measured; according to the value of this resistance so a greater or less deflection is obtained on the milliammeter needle. The scale is calibrated in ohms instead of in milliamps and suitable devices are incorporated in the circuit of the instrument itself to ensure that the calibration shall, as far as possible, be independent of the voltage of the battery within fairly wide limits.

The ohmmeter was popularised by Messrs. the Automatic Coil Winder and Equipment Co., who have marketed for years an instrument known as the Avometer. This is a composite instrument giving various ranges of current and voltage, together with a resistance range covering the values required in ordinary practice.

This instrument is made for d.c. only or as a combined a.c. and d.c. instrument. In the latter case a rectifier is used for the a.c. ranges, brought into circuit as required by the switching.

There are various forms of ohmmeter circuit designed to compensate for changes in the voltage of the battery. A typical circuit is shown in Fig. 2.3. In series with the meter is a resistance *R* (usually chosen to be equal to the resistance to be indicated at mid scale), while across the meter is a variable resistance *S* brought out to a small knob or adjusting screw on the surface of the instrument. When the terminals are short circuited the resistance S is varied until the meter reads full scale deflection (corresponding to zero ohms). Under these conditions the current is $I_1 = E/R$ (neglecting the resistance of the meter with the shunt across it which will in any case be small compared with R).

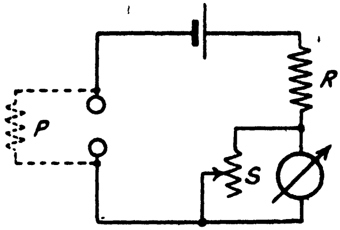


Fig. 2.3. Circuit of Typical Ohmmeter.

Now if we connect a resistance P across the external terminals we shall have a current $I_2 = E/(R+P)$. From these two equations we can obtain an expression of P in terms of R, the actual expression being $P = R(I_1/I_2 - 1)$. It will be seen that the expression depends upon R, which is known, and on the *ratio* of the two currents. Consequently the actual value of the current is immaterial and it is only necessary to adjust the shunt resistance so that it reads full scale deflection with the test terminals short circuited, an adjustment which will require occasional resetting as the battery voltage changes due to age.

The designer of the instrument choses the resistance R to give him the particular range of resistance which he requires, and, as the reader will probably be aware, the ohms scale is not by any means uniform but is much more open at the low values of resistance and becomes progressively more crowded at the higher values. Actually this is an advantage because it tends to give a constant percentage reading accuracy. Some types of instrument incorporate switching so that the resistance R can be changed, thus providing two or three ohm ranges, usually in a ratio of 10:1 so that the same scale serves.

Thermal Meters. For accurate measurement of alternating current thermal meters are the most satisfactory. These meters depend upon the heating effect of the current and are of various types. The simplest form of thermal ammeter is the hot wire ammeter which is still occasionally used for crude measurements and consists of a thin filament of wire which is kept taut by a thin silk thread kept in tension by a spring (Fig. 2.4). This thread passes round a spindle to which a pointer is attached so that any movement of the thread is translated into rotational movement of the pointer. The passage of current through the wire causes it to sag, due to the expansion under the influence of the heat. This sag is taken up by the silk thread, and in doing

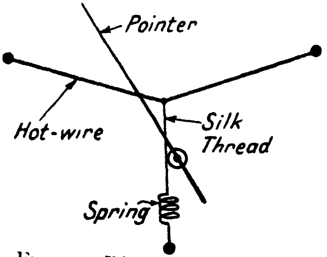


Fig. 2.4. Diagram of Hot Wire Ammeter.

so it causes the pointer of the meter to move, indicating the amount of the current.

This form of meter is not very accurate because it is sluggish in action and is liable to stickiness, so that the pointer does not always indicate the same reading for the same current, nor does it always come back accurately to zero.

A more convenient type of thermal instrument where reasonable currents are to be dealt with is the vacuo-junction type. Such instruments incorporate a vacuum-enclosed thermocouple which is a device in which the junction of two dissimilar metals is heated by a separate heater wire which may or may not actually make contact with the thermocouple itself. The effect of the heat is to develop a small voltage which is proportional to the temperature, and the materials chosen are such as to give the maximum thermo-electric voltage consistent with other requirements such as low contact potential.

The voltage which is developed by the thermocouple is only a few millivolts, and this is passed through a sensitive microammeter which is calibrated in the terms of the current through the heater of the device. Since the heating effect of the current is proportional to the square of the current the instruments have a square-law scale, giving small readings for low currents and increasingly large readings as the current rises. They are also subject to the defect that they will carry very little overload because the heater wire has to be made so fine that an excess current very quickly burns the filament out altogether.

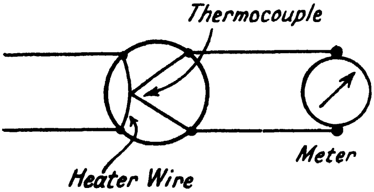
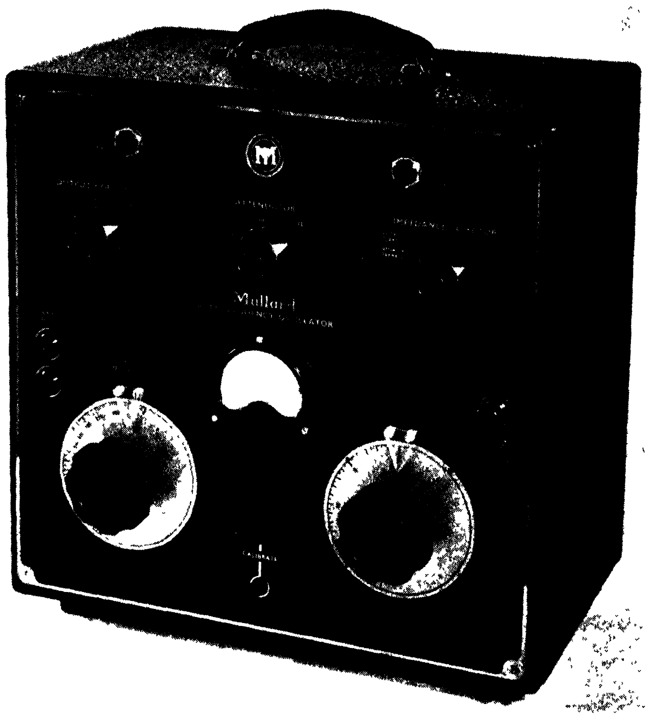


Fig 2.5.
Illustrating use of vacuo junction for measuring small A.C. currents.

Sometimes the thermocouple, which is quite small in physical dimensions, is housed inside the meter itself. At other times the thermocouple is used as a separate unit and leads are taken to a suitable meter. This technique is adopted in the laboratory and has the advantage that one indicating meter can be used with a variety of thermocouples having different current ranges.

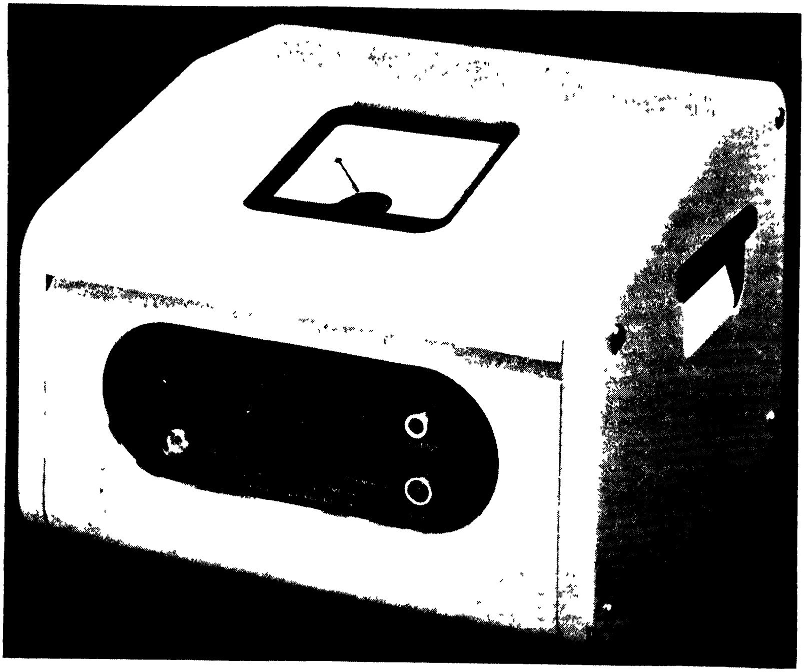
For heavy currents the thermocouple is exposed to the air, although suitably protected against draughts and mechanical damage, but for currents of less than one ampere down to a few milliamperes the whole assembly is enclosed in a glass bulb from which air is exhausted. Such devices are often known as vacuo junctions. The purpose of removing the air is to reduce the radiation of heat from the heater wire so that the thermocouple itself shall receive the full benefit of the heat developed and actually the sensitivity is increased some fifty times by this technique. The table herewith indicates the characteristics of some representative vacuo junctions.

PLATE V



This Mullard Beat Frequency Oscillator delivers audio-frequency output over a range of 25–20,000 c/s. It incorporates a built-in attenuator and is matched for a range of impedances.

PLATE VI

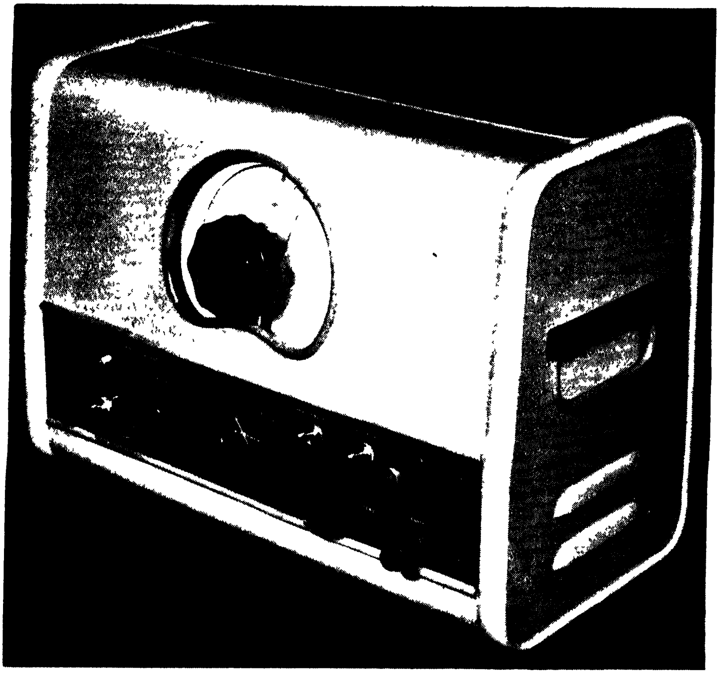


The Furzehill Sensitive Valve Voltmeter shown here is a high-impedance amplifier voltmeter measuring from 1 mV to 100 V over a frequency range from 20 c/s to 0 5 Mc/s

PLATE VII

This Taylor Electronic Test Meter is a combination of a diode voltmeter for signal measurements and a multirange test meter for voltage and current measurements. The probe in the foreground is used for r.f. tests to avoid loading the circuit with too much capacitance.

PLATE VIII



This Furzehill Beat-Frequency Oscillator is a small precision oscillator covering 20–20,000 c/s with a logarithmic scale and less than 0·5% hum and harmonic content.

TABLE II.

CHARACTERISTICS OF TYPICAL VACUO JUNCTIONS (CAMBRIDGE INSTRUMENT CO. LTD.).

Heater Resistance (ohms).	Couple Resistance (ohms).	Current (mA) for open circuit e.m.f. of 6 mV.
1,600	13	1·25
400	8	2·5
90	8	5
30	8	10
12	4	25
4	4	50
1	4	150
0·4	4	500
0·2	4	1,000

Characteristics of A.C. Meters. Reference has already been made to the dependence of the rectifier type of meter from the waveform. It is convenient at this point to interpose a few observations on the relative accuracy of different types of a.c. meter.

A.C. theory is based fundamentally upon the assumption of a particular form of alternating current known as a sine wave. With this form of wave the current or voltage is of the form $i = I \sin \omega t$ where $\omega = 2\pi$ times the frequency of the oscillation. The reason for adopting this particular form of current is discussed in textbooks dealing with radio theory, and all that need be said here is that this is the form of voltage generated by a simple alternator, and it is indeed the natural form of oscillation which is generated in an electrical circuit.

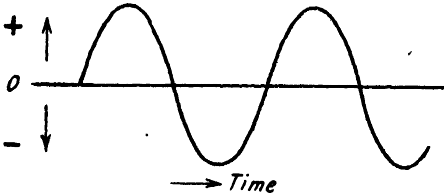


Fig. 2.6. The ideal current wave is of sine formation as shown here.

With this sine waveform of current or voltage we have a gradual rise to a maximum, followed by a symmetrical fall through zero to a maximum in the opposite direction and then a return to zero again after which the whole cycle is repeated. The form of current is illustrated in Fig. 2.6. Under many conditions we find that the waveform with which we are dealing is distorted. If a valve in the circuit is not operating correctly it is possible for certain parts of the wave to be transmitted satisfactorily while others are either accentuated or restricted. The presence of iron cores in inductances will often cause distortion of the waveform and in general a pure sine wave is something which can only be produced or preserved at the expense of considerable trouble. Moreover, as the reader will be aware, the waveforms of the current corresponding to speech or music are very far from pure sine waves, being made up of fundamentals with a large percentage of overtones or harmonics so that in general a sine wave is the exception rather than the rule.

Now the measurement of an alternating current or voltage involves a certain amount of assumption. Since even the relatively low frequency alternations of the electric light mains take place at the rate of 50 cycles per sec., which is faster than the eye can follow, it is necessary to adopt some mean or average value of the current or voltage as a measure of its strength. The actual average value of course, is zero because the positive and negative half cycles are equal and opposite. Therefore, the first requirement is that we must either use a device which is not dependent upon the direction of the current or we must arrange to rectify the current.

Moving iron and thermal meters belong to the first class for the magnetic attraction of a coil on a piece of soft iron or the heating effect of a current are both independent of the direction of the current (being actually proportional to the current squared). If we pass an alternating current through a piece of wire it will go through a series of heating cycles in which the heat generated varies between nothing and a peak value, but because of the thermal inertia of the wire it will retain some average heat which we could use as a measure of the current (and actually do as has already been explained).

R.M.S. Value. This has led to the adoption of the *root mean square value* of the current which is an average value based on the heating effect produced. We say that an alternating current and a direct current are equivalent in strength if they both produce the same average heating effect, and our estimates of the strength of alternating currents are therefore based on this r.m.s. value as it is called.

The term "root mean square" is an abbreviation for the square root of the mean of the sum of the squares. The heating value of the current at any instant is proportional to the square of its instantaneous value. If we take the successive instantaneous values of the current over a complete half cycle, square all these instantaneous values, take the mean or average value of these squares and then take the square root of this mean we obtain the equivalent steady current which would produce the same heating effect as the half cycle of alternating current in question.

With a sine wave it is possible to calculate the r.m.s. value in terms of the maximum or peak value of the current, and we find that it is $1/\sqrt{2}=0{\cdot}71$ times the peak value. If we are using a moving iron or thermal meter the indication given by the meter is truly the r.m.s. value because the instrument actually measures the r.m.s. value of the current or voltage irrespective of the actual shape of the waveform.

With a wave which is flattened at the top we find that the r.m.s. value is more than 0·71 times the peak value, while with a wave which is peaky the r.m.s. value is less than 0·71.

Now when we use rectifier meters the current which flows is no longer proportional to the square of the current. It is actually proportional to the average value of the (rectified) current, which in some respects is an advantage because the scale is reasonably linear instead of being of a square-law type. The average value of a rectified sine wave, however, is not the same as its r.m.s. value, being $2/\pi = 0{\cdot}64$ times the peak value, so that the indication given by a rectifier meter will, unless some allowance is made, be in error by some 11 per cent. Actually this is taken into account when the instrument is first calibrated and its calibration is based on the assumption of a sine wave current.

Unfortunately this assumption is only correct for a pure sine wave, and if the waveform is seriously distorted the indication given by the meter will be appreciably in error. A wave which is flat topped will give too low a reading, and a wave which is peaky will give too high a reading, although no hard and fast rule can be laid down because everything depends upon the form of the actual distortion, and the influence it has on the *form factor* of the wave, which is the term used to indicate the ratio of the r.m.s. to the mean value.

For some purposes it is more convenient to indicate the peak value of the voltage or current, which can be done by a valve voltmeter, but this question is discussed more completely in Chapter III.

Effect of Frequency. There are certain other effects which are worth bearing in mind when dealing with a.c. meters. The first is the possible influence of frequency on the meter. A moving iron meter, for example, is only satisfactory at power and low audio frequencies. As the frequency rises the magnetic losses in the structure very quickly reduce the effectiveness of the operation and the reading falls off quite rapidly.

With rectifier instruments frequency error is not serious until one reaches frequencies of the order of 50–100 kc/s. Special very small rectifier elements have been developed for meter practice in which the self capacitance of the rectifier elements is minute, and this enables the accuracy of reading to be maintained up to frequencies of this order. Thermal instruments are satisfactory up to radio frequencies of the order of 20–30 Mc/s, beyond which point the self capacitance of the leads to the heater, short though they may be, is sufficient to by-pass some of the current and the indications become increasingly inaccurate. Special technique is available for dealing with very high frequencies, but this is beyond the scope of this work.

With a d.c. meter it is possible to connect simple shunts externally in order to reduce the sensitivity but this technique must be adopted cautiously with a.c. meters. It is not feasible with rectifier meters unless these already have some shunts incorporated, because of the varying impedance of the rectifier as explained in the next paragraph, while shunting of a vacuo junction is only feasible at low radio frequencies. Otherwise the self inductances and capacitances of the leads alter the current distribution so that the shunting action is not the same at radio frequencies as it is on d.c. on which the instrument is usually calibrated.

Variation of Impedance. A further point to be considered in connection with rectifier instruments is the fact that the impedance of the rectifier itself is not constant but decreases as the current through the rectifier increases. With a voltmeter, which has a large series resistance in any case, the impedance of the rectifier is small in comparison with the total swamp resistance so that the effect is negligible and the calibration is linear, as it would be with a d.c. meter, but for low values of voltage the series resistance necessary is too low to be able to swamp the rectifier impedance satisfactorily, and the scale shape becomes crowded at the lower end of the scale. This effect is dealt with in the literature issued by the Westinghouse Brake and Signal Co., who manufacture the copper oxide rectifiers used for this purpose, and as a general rule it can be taken that for voltages below about 10 volts a non-linear scale begins to be apparent. Moreover, the resistance of the rectifier itself is not constant but varies quite appreciably with temperature so that the calibration of the meter cannot be relied upon for these low voltages.

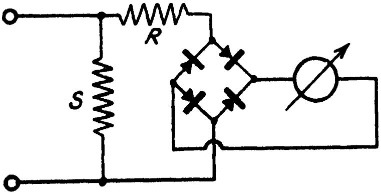


Fig. 2.7. Method of Increasing the range of a Rectifier Milliammeter.

The same applies to rectifier milliammeters of low reading—i.e. where the rectifier is directly in series with the meter. The effect here is not so much a non-linear scale as a change in the overall impedance of the instrument which is in any case much higher then for a corresponding d.c. meter. A 1 mA a.c. rectifier movement, for example, has a resistance of the order of 300 ohms at full scale deflection rising to 600 or 1,000 ohms at one-tenth of full scale.

Shunting of a rectifier movement is not satisfactory mainly because of the temperature variation already mentioned, though it is possible to compensate for this in some measure by a combination of series resistance with a shunt across the whole network. When it is desired to increase the reading of a rectifier milliammeter, however, the best method is to turn it into a millivoltmeter as shown in Fig. 2.7. Here the main current flows through the resistance *S* and develops a voltage across this, which is applied across the meter in series with the rectifier and a series resistance *R*. This series resistance tends to swamp the variations of rectifier impedance so that for currents above 25 milliamps it is possible to obtain a linear scale once again.

Still another method is to use a current transformer which is a transformer having a small number of turns on the primary and a much larger number of turns on the secondary. This increases the voltage available and permits the use of a large enough series resistance to swamp the rectifier variations. This is, indeed, the most satisfactory method of obtaining a multi-range a.c. meter since an instrument constructed on these lines holds its calibration very well.

Care of Meters. From what has been said it will be clear that for accurate results the meter will not be cheap. It behoves the user therefore to take care of his instrument. The main source of damage is overloading, for an excessive current will cause the meter to deflect hard over causing a severe shock to the delicate pivots and springs. Even though the overload may only be momentary, the jar to the system causes damage which results in a gradual loss of accuracy, a "stickiness" in the movement, and a general deterioration.

Hence before making any measurement, pause to make sure that the instrument is not being risked. With a multi-range test set, make sure the switch is set for volts before connecting the leads across a high voltage. It is quite easy to forget that the previous measurement was a current (or perhaps a resistance) check and omit to change the switch. A safe rule is always to return the switch to the maximum *voltage* setting, for in this condition the possibilities of overload are very few.

When measuring currents, set the instrument to a higher current than is expected and then come down if the reading is too small. When looking for faults the current may easily be more than you anticipate.

For certain types of test a protective rectifier may be used. It has already been mentioned that the resistance of a rectifier falls as the voltage across it increases. It is possible to use this effect to act as a variable shunt across a meter.

A typical example is a 5 mA moving coil movement with a 1 ampere rectifier across it. At small currents (say 0·1 mA) the voltage across the rectifier is so small that its resistance exercises a negligible shunting action on the meter which thus operates with normal sensitivity.

As the voltage across the meter rises the rectifier resistance falls so that it shunts the meter and diverts part of the current. This effect is cumulative until when the meter is reading full scale the current through the rectifier shunt is perhaps 200 times as great as the meter current.

The meter thus has a compressed scale, reading up to 1 mA over the first fifth of the scale and yet requiring 1 ampere for full scale. The actual scale depends upon the relative resistances of meter and rectifier and a selenium rectifier is particularly useful for this type of usage. The accuracy is reduced because the shunting action of the rectifier is liable to vary with temperature, but the device is useful in providing a much more "universal" meter and one which is less liable to damage by overload.

The meter should include a series resistance of 150 to 300 ohms, and the rectifier should be a Westinghouse LT4, or a Standard Telephones V45-1-2-B1 or similar type. The arrangement was described in an article in *Wireless World*, January 11, 1935.

CHAPTER III

GENERATORS AND INDICATORS

IN this chapter we will discuss in greater detail the auxiliary equipment used for generating test voltages and the apparatus used for indicating the voltage developed by the receiver.

Signal Generators. The most important item is the signal generator which comprises a multi-range oscillator, usually provided with a series of self-contained coils selected by means of a switch and tuned with a variable condenser. The output voltage from this oscillator is fed through an attenuator into an output cable, the far end of.which is connected to the receiver.

The essential requirement for a signal generator is that the output voltage shall be under complete control. It is customary to measure the voltage at the input to the attenuator, at which point it is of the order of one volt which can conveniently be measured. Beyond this point the output is cut down progressively by the attenuator, which is calibrated accordingly.

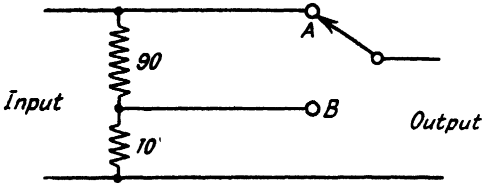


Fig. 3.1. Simple Step Attenuator.

Fig. 3.1 illustrates a simple type of attenuator in which the voltage at the point *B* is one-tenth of the voltage at point *A*. Fig. 3.2 shows an extension of this idea in which four steps are provided, each giving one-tenth of the voltage on the preceding step. Consequently if we start with one volt we shall have 100 microvolts on the last step. This type of circuit is called a ladder attenuator and the resistance values are chosen so that they comply with the requirements that the effective resistance decreases progressively in steps of 10–1.

For example, the resistance at the output end *AB* is one-tenth of the total resistance between *A* and *C*. Going one stage farther back we have the resistance *DC* of 12·2 ohms which is shunted with the resistance between *A* and *C*, totalling 110 ohms; these two in parallel again give us 11 ohms. Therefore, the network *ECD* looks exactly the same as the network *CBA*, each providing a step down of ten times.

Similarly a calculation will show that the resistance between the points *A B* with all the rest of the network in parallel comes down to 10 ohms, and the same applies between the points *CD* and *EF*. Consequently on the second, third and fourth position of the switch the attenuator looks like 10 ohms, viewed from the output end. On the first position of the switch the resistance will be higher, being 110 ohms shunted by whatever resistance there is on the input side, but on the highest tapping of any attenuator a higher internal resistance is usually permissible.

It will be noted that the accuracy of the attenuation depends on the assumption that the load which is connected across the output terminals is of high resistance. In practice we connect this either to the grid of a valve or across a tuned circuit which looks like a resistance of hundreds of thousands of ohms or we connect it through a dummy aerial for connection to the aerial terminals of a receiver. In all these cases the conditions are complied with and the attenuator operates satisfactorily.

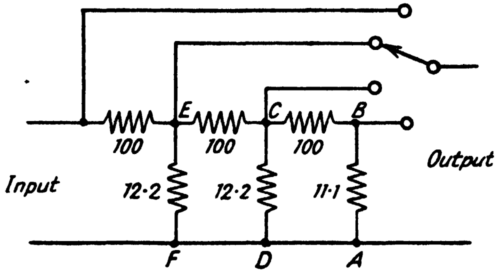


Fig. 3.2. Three-step 10 ohm Attenuator.

Now the arrangement of the resistances in the attenuator network, including the switch, must be very carefully carried out, because if there is appreciable capacitance between the various sections some of the current will be diverted from its proper channels. This may have the effect of passing energy from one section to the next so that the voltage is not reduced by 10–1 but by some lesser amount. Alternatively, although more rarely, the shunting action may tend to increase the attenuation and in any case these inaccuracies become increasingly noticeable as the frequency of the current increases, so that an attenuator which is quite satisfactory up to a megacycle may become more and more inaccurate until at 25 megacycles it is providing attenuation of perhaps 2–1 instead of 10–1.

Moreover, these errors are usually cumulative. The early steps of an attenuator may behave satisfactorily even at quite high frequencies while the later steps may fail to attenuate at all. This latter effect is due to leakage and earth currents. Obviously if the oscillator in the signal generator is not adequately screened the direct radiation can be picked up by the receiver under test and this will add to the voltage which comes through the attenuator giving more output from the receiver than it should do. The leakage will be a small percentage of the total when the output is large, but will become increasingly noticeable as the output is reduced.

This form of difficulty, however, is fairly easily overcome, but there is a further trouble which is much more difficult to remove, and that is the presence of earth currents in the output cable. Fig. 3.3 illustrates this point. Here we have represented a tuned circuit which is maintained in oscillation by a valve (not shown for the sake of clearness) and coupled to this is an output coil delivering voltage at the point *O*. This voltage is fed through the attenuator *CBA*, and the output cable which collects the voltage is shown connected to the point *B*. Now if *AB* is, say, one-hundredth of *AC* we should expect the voltage to be cut down by 100 times.

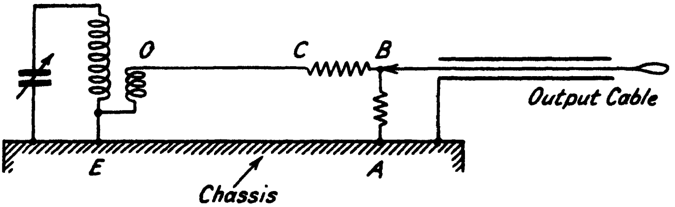


Fig. 3.3. Illustrating Error Introduced by Incorrect Earthing.

Actually it will be seen that the current having passed through the attenuator has to return back to its starting-point via the portion *AE* of the chassis. Now this path will produce quite an appreciable voltage drop. Even though the chassis may be of apparently low resistance material the inductance of the circuit is sufficient to provide quite considerable voltage drop—considerable, that is, in comparison with the microvolts with which we are dealing. In the circuit shown it will be possible to obtain quite a large voltage output with the output cable at the point *A*, whereas theoretically the output at this point should be nothing.

It will be noted that this effect becomes more serious as we reduce the output voltage and it is this in fact which is largely responsible for the failure of attenuators to give their proper reduction in output at the lower outputs, particularly as the frequency increases, because the voltage drop due to inductance at the path *AE* becomes greater as the frequency rises.

Re-arrangement of the circuit as shown in Fig. 3.4 overcomes the difficulty, the point being that all the earth points are taken to one actual physical point in the layout of the job and this single point is then connected to the earth terminal on the chassis. In some cases the chassis itself is isolated though this is usually not essential except at frequencies above 25 Mc/s.

The magnitude of the problem is indeed dependent upon the standard of performance aimed at. With first-class signal generators where an output of a genuine microvolt is required even at the highest frequencies, considerable research work is necessary in the preparation of the design in consequence of which (having regard to a similar precision in other parts of the equipment) the cost runs into several hundred pounds. As the performance specification is relaxed the cost falls rapidly and simple service signal generators, or modulated oscillators as they are often called, are available at prices between £10 and £20. The accuracy of output of these simple types of instruments may easily be as much as 20 per cent in error and even 50 per cent at the highest frequencies, but they are not intended for accurate measurement but merely as a source of controllable signals and as such they are perfectly satisfactory. The laboratory worker requires something better and according to the exactitude of his requirements he will have to pay something in between these two extremes.

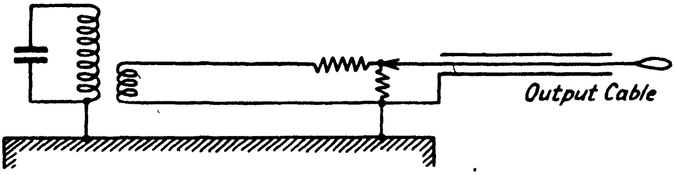


Fig. 3.4. Correct Method of Connecting Output Circuit of Fig. 3.3.

Variable Attenuators. The attenuators discussed so far have been of the fixed or step type, but in order that the output shall be continuously variable it is necessary that some small variable section shall be provided which will give a continuous change of output voltage over a range of 10–1. This may be done a variety of ways. One is to make the end section in the form of a variable resistance of the slide wire type, in which case the ladder attenuator preceding it has to be slightly re-arranged as shown in Fig. 3.5. Another arrangement is shown in Fig. 3.6, where the variable section takes the form of a potentiometer on the input. This arrangement has the advantage that the output impedance of the network is not affected by the setting of the variable section, and with the arrangement shown the input impedance is also constant within quite small limits, because the potentiometer is tapped at various points and resistors connected to ground so that in itself it constitutes a ladder attenuator with the advantage that a variable connection can be made to any point on the top arms.

There are other forms of variable attenuator which need not be discussed here. As a general rule it is important that the input impedance of the attenuator shall be tolerably constant because the frequency generated by the oscillator depends to a small extent upon

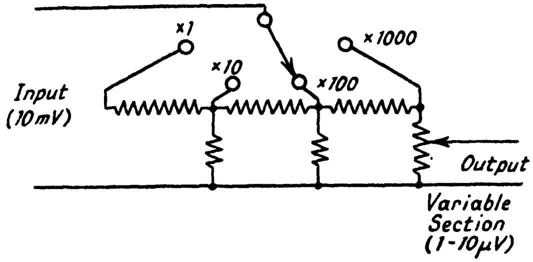


Fig. 3.5. Attenuator having a Variable Section in Addition to the Fixed Steps.

the resistance which is connected across the output coupling coil, and if this is subject to large variations then the frequency will change according to the setting of the attenuator. This will involve a continual re-tuning of the receiver or circuit under test which will become very tedious (while if the point is not appreciated the results obtained may be quite incorrect).

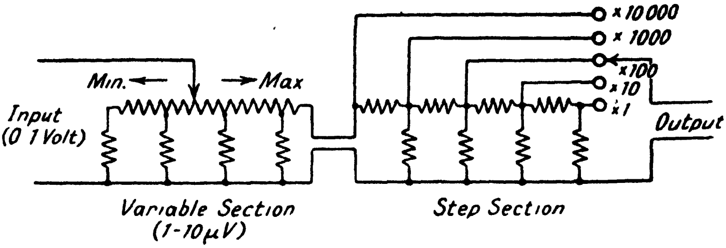


Fig. 3.6. Alternative arrangement to give continuous attenuation.

Measurement of Output. The actual voltage at the input of the attenuator may be measured in two ways. We may either measure the current into the attenuator network and by multiplying this by the input resistance of the attenuator we can arrive at the voltage. The current therefore is adjusted to a given reading of the meter scale such that the voltage across the attenuator input is some given figure, say, one volt.

The meter used for such a purpose would be a thermo-ammeter of the vacuo junction type. The method assumes that the input resistance of the attenuator remains constant at all settings.

The other method is to measure the voltage actually across the attenuator input with some form of valve voltmeter. As is explained later in the chapter the indication given by a valve voltmeter depends upon its type. In general they tend to give a peak indication—i.e. to respond to the peak value of the voltage, so that if the waveform of the oscillator output is not pure the indications obtained may be misleading. What is more important, the waveform of the oscillator is liable to change according to the setting of the variable condenser which is used to tune it so that the error in reading is variable and in particular it may be found that results obtained with the oscillator set near the minimum on one range will not agree with results obtained at the same frequency provided by a setting towards the maximum of the preceding range because of the difference in the operating characteristics of the oscillator.

If a valve voltmeter is used, therefore, it should be of a type which gives a reading dependent on the average value, which is a better approximation to the r.m.s. value than is obtained with a peak reading instrument.

These matters are admittedly questions largely of design but the difficulties which exist should be appreciated by the user. It is a simple matter, for example, to test a signal generator when it is first used to make sure that the readings obtained are consistent, particularly at the ends of the scale where some overlap is provided for convenience so that it is possible to obtain the same frequency on two different ranges. A check should be made to see that when the generator is ostensibly set to give the same output that the indicator on receiver or other device to which the generator is connected does give the same reading on the two possible settings. Failure to do this will certainly hamper accurate measurements. The difficulty may arise from unsatisfactory metering as just described or from incorrect modulation. It is as well to consider this point next.

Modulation. A signal generator may be used for pure radio frequency tests in which case the carrier does not require to be modulated, but if, as is often the case, one is making a complete check of a receiver including the detector stage it is necessary that the signal shall be modulated. It is customary, therefore, to include a small audio-frequency oscillator and to arrange that this can modulate the radio-frequency oscillation. In high grade signal generators this modulation is variable in extent and means are provided for measuring the depth of modulation. In simpler types of service instrument the modulation is fixed at some arbitrary figure, usually 30 per cent. The depth of modulation is not likely to stay constant as the tuning dial of the signal generator is rotated, but with reasonable precautions in design it is possible to ensure that this modulation depth does not change seriously and remains within the limits of perhaps 25 per cent to 35 per cent at any setting on the instrument.

This is quite satisfactory for fault testing and for simple checks on gain. For accurate work, however, it is necessary that the modulation shall be more accurately known, and moreover that it shall be capable of variation between, say, 0 and 50 per cent. Sometimes it is desirable to modulate practically to 100 per cent, but if this is to be done the modulation equipment has to be increased in size or complexity.

The simplest form of modulation is the Heising or choke modulation system illustrated in Fig. 3.7. The oscillator valve is on the right and the h.t. supply to the anode is fed through an iron cored choke. This same choke, however, also feeds the modulator valve which is designed to take considerably more current than the oscillator, so that the voltage at the point *A* is controlled largely by the variations of anode current of the modulator valve. If this valve is fed with audio-frequency voltages from a small a.f. oscillator the h.t. of the r.f. oscillator valve will vary in accordance with the audio-frequency modulation and this will cause its amplitude to vary. With suitable choice of operating characteristics the oscillator output can be made directly proportional to the oscillator h.t. voltage, so that we shall obtain a linear modulation of the amplitude at the frequency of the applied audio-frequency signal and to a depth which is controlled by the voltage applied to the grid of the modulator.

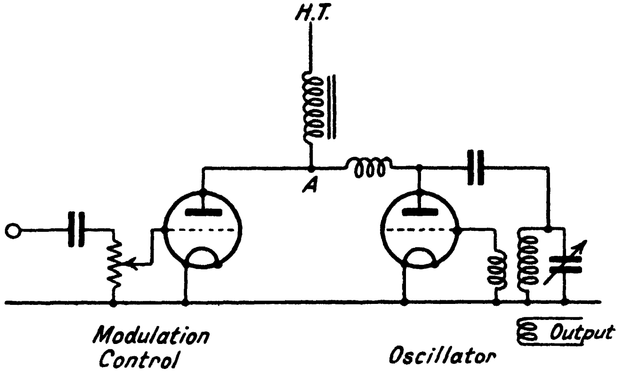


Fig. 3.7. Heising Modulation Circuit.

Owing to the fact that, from considerations of economy of operation, the valves in a signal generator are kept as small as possible, this form of modulation can only be used successfully for low modulation depths. If it is to be used for higher depths of modulation the power of the modulator stage must be increased considerably and the whole equipment becomes larger. The most serious disadvantage of a choke modulated scheme, however, is that the variation of h.t. voltage not only varies the amplitude of the r.f. oscillation but also its frequency.

Frequency Modulation. With an insensitive receiver having fairly broadly tuned circuits this consideration is not troublesome. The frequency swing may perhaps be 0·1 per cent at a modulation depth of 30 per cent, which only represents a small amount of mis-tuning. The modern receiver, however, contains highly selective circuits often having a total acceptance band of little more than 5 kc/s. A swing of 0·1 per cent at 10 Mc/s corresponds to 10 kc/s so that the frequency would swing right out of the pass band of the receiver.

The rise in amplitude of the carrier due to the modulation will be offset by the reduced response of the receiver due to the frequency swing, while when the carrier amplitude is reduced the receiver output will fall more than it should do. The result is asymmetrical modulation and the reading of any output meter in the receiver will become meaningless.

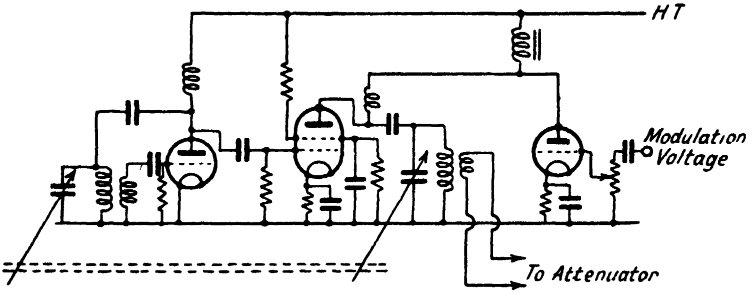


Fig. 3.8. Circuit using Buffer Amplifier. Applying the Modulation to the Amplifier avoids any appreciable change of Frequency with modulation.

The degree of frequency modulation produced depends largely on the operating conditions of the oscillator valve, so that it may well be found that with the receiver unchanged but the input signal obtained by two different settings of the signal generator, one at the bottom of one range and the other at the top of the preceding one, the results may be quite seriously different.

This is another reason for checking the performance of a signal generator when it is first put into commission. Frequency modulation is aggravated in many signal generators, particularly of the inexpensive service type, by virtue of the fact that low h.t. voltages are used in the interests of economy of consumption, but even quite expensive signal generators are found to possess this defect to a marked extent and there is a tendency to-day to use alternative forms of modulation.

The most satisfactory method is to use a buffer amplifier in which the original radio-frequency oscillation is passed through a tuned amplifying stage which is then modulated either by choke modulation as before or by variation of the screen or suppressor voltage of the amplifier valve or both. In this way the modulation does not react on the primary oscillator and frequency modulation is greatly reduced. The complexity and hence the cost of the instrument is, of course, substantially increased by this procedure which is another reason for the increased expense of standard signal generators as against modulated oscillators.

Another point of importance is the symmetry of the modulation. With a correctly modulated wave the carrier amplitude increases and decreases by equal amounts, *leaving the mean value of the carrier unchanged*. All too often the effect of modulation is to reduce the carrier but not increase it appreciably so that the mean value of the carrier drops, which reduces the effective output and so causes inaccurate readings. This defect is often accompanied by bad modulation waveform, which invalidates the readings of the output meter on the receiver. The effects are shown in Fig. 3.9. They are only important in serious measurement, but show why good signal generators are so much more expensive.

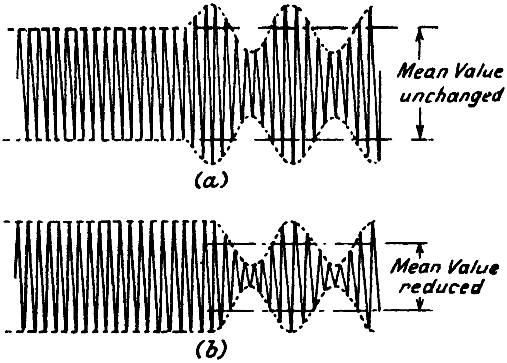


Fig. 3.9. For Correct Modulation the Mean Value of the Carrier should not alter.

Measurement of Modulation. The measurement of the modulation is an important one because it is necessary not only that the measurement shall be accurate, but also that any given test may be repeated at some future date. For example, in the analysis of detector performance the audio-frequency output is plotted against radio-frequency input with varying degrees of modulation and any inaccuracies in the modulation depth will, of course, produce large differences in the output.

Where an actual measurement of the oscillating current is being made it is possible to assess the modulation by noting the increase in current when the modulation is switched on. Although the mean current remains the same, the effective or r.m.s. value increases because of the higher peaks of current when the oscillation is modulated. In point of fact, if I_1 is the current with no modulation and I_2 is the current with modulation applied, then the percentage modulation is given by

$$M = \sqrt{2\left(\frac{I_2^2}{I_1^2} - 1\right)} \times 100$$

The method is not reliable if the output indicator is of the voltage type (e.g. a valve voltmeter), because such devices do not read true r.m.s. value.

The following table is of use:

TABLE III

INCREASE OF CURRENT WITH MODULATION

Percentage modulation.	Percentage increase in current.
20	1·0
30	2·2
40	4·05
50	6·1
80	14·9
100	23

This method, of course, has the disadvantage that if the modulation is small the increase in deflection is negligible. Actually, however, the increase becomes appreciable at about 30 per cent, and thereafter increases quite rapidly.

In some types of signal generator the input control to the modulator valve is calibrated in terms of modulation depth. It is then set to some high value, say 50 per cent, and an auxiliary control adjusted until the modulation rise on the carrier meter is correct. Thereafter the calibration of the control knob is assumed to be correct.

This method is liable to give misleading results if the circuit is not modulating properly. It is advisable, where possible, to check the modulation oscillographically as explained in Chapter XII, but if this is not practicable a check on the modulation should be made by two or more alternative methods, to see whether they agree.

An alternative method for measuring the modulation which can be used when a choke modulation is employed is to measure the audio-frequency voltage developed across the modulating choke.

For linear modulation the oscillator output should be proportional to the d.c. anode potential. Then if the modulation causes this potential to vary between, say, 0·5 and 1·5 times normal we shall obtain 50 per cent modulation. Under these circumstances the peak value of the *modulation* voltage will be equal to 50 per cent of the steady anode potential.

Thus the peak value of the modulation voltage provides a measure of modulation depth as long as linearity exists between oscillator output and anode voltage, which can be achieved reasonably easily up to about 80 per cent modulation depth. Hence a meter reading the a.c. modulation voltage and adjusted to give full scale deflection with, say, $0{\cdot}8\, V/\sqrt{2}$ volts (where V is the d.c. anode potential) would indicate 80 per cent modulation depth at full scale and in linear proportion for smaller readings.

If the d.c. anode potential is liable to variation a shunt may be arranged across the meter which is then used with a suitable (different) series resistance as a d.c. voltmeter to check the steady anode potential. The shunt is adjusted so that the meter reading on this test position always coincides with a given mark and this adjusts the meter sensitivity so that the modulation measurement is correct.

Direct Methods. Still another method is to measure the audio-frequency voltage developed at the output of the generator and to compare this with the r.f. carrier. This is really the most accurate method of all because it is a definite measurement of the modulation and not of something in the circuit which ought to be proportional to the modulation if everything is correct. One possible method is to measure the peak voltage of the unmodulated carrier with a diode voltmeter and then measure the audio-frequency component developed across the load by an ordinary valve voltmeter. Fig. 3.10 shows a circuit for doing this.

This method assumes a good r.f. waveform which is not always justifiable, while the a.f. voltage developed is only a small fraction of a volt.

A better method is to "hook up" an amplifier to increase the voltage available. This amplifier may be a single stage using a high slope pentode. This enables the tuned circuits to be deliberately damped so that the effect of any frequency modulation is negligible.

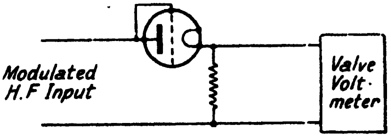


Fig. 3.10. Use of Diode to Measure Modulation.

The r.m.s. radio-frequency voltage across the circuit is then measured by a thermal meter. This can conveniently be a vacuo junction in series with a resistance, this resistance serving as the damping resistance required across the circuit as explained above.

The modulation voltage is then measured by connecting a diode across the circuit and noting the a.f. voltage developed with a valve voltmeter. The arrangement is shown in Fig. 3.11.

If an amplifier such as this is constructed, however, the output voltage will be sufficient to apply direct to the plates of an oscilloscope and the modulation depth can then be read directly from the pattern produced, as described in Chapter XII, to an accuracy of a few per cent.

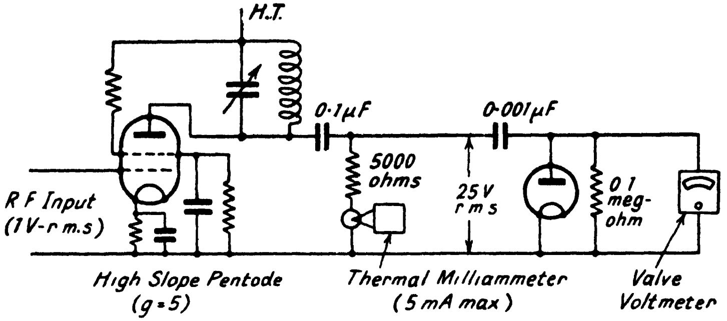


Fig. 3.11. Illustrating Use of Amplifier to Reduce Error in Modulation Measurements.

Audio-Frequency Oscillators. A simple audio-frequency oscillator can be constructed using an inductance and capacitance as with a radio-frequency circuit, but this method is seldom used except for fixed frequencies. The reason is that even using inductances of quite large value the capacitance required to tune to an audio frequency are of the order of ·01 to ·1μF. Such capacitances are not easily made variable so that the oscillator cannot be altered over a wide range of frequency without recourse to some system of switching by means of which a large number of condensers are connected in sequence, and each one of these has to be individually adjusted to give the frequency required. Moreover, the use of iron-cored inductances is almost essential because of the large inductance required, and this is liable to introduce distortion into the waveform unless the oscillation can be restricted to quite a small amplitude.

The most usual method, therefore, is to adopt what is called a beat-frequency oscillator. Here two radio-frequency oscillations are generated, having a frequency usually between 40 and 100 kc/s. One of these oscillations is kept fixed while the other is variable over a small range. If these two oscillations are fed to a mixing circuit of the conventional type, beat tones are produced at a frequency equal to the difference between the component radio frequencies. Thus if one frequency is fixed at 100 kc/s and the other is variable over a range of 100–115 kc/s, the difference tone produced will vary from 0–15 kc/s which covers the greater part of the audio-frequency range. A radio-frequency oscillator to vary over a limited range like 100–115 kc/s is quite easy to produce so that the device gives a convenient and practicable method of obtaining a large audio-frequency variation.

It is not possible to reduce the frequency to zero because when the two oscillators are very close in frequency it will be found that the stronger oscillator pulls the weaker oscillator into step. The frequency difference before this occurs depends upon the design of the instrument. The two individual oscillators should be shielded from one another and stray couplings between them avoided. With fairly simple precautions it is possible to get within 50 or 100 c/s, but to obtain lower beat frequencies requires considerable attention to detail in the design.

If there is appreciable interaction between the oscillators the waveform of the beat output will be seriously distorted long before the oscillators finally pull into step, and this is obviously undesirable. Given correct design the output from a beat-frequency oscillator can be made particularly pure so that the harmonic content in the output is controlled more by the distortion in the output valve than any defects in the mixing process.

The actual form of mixer depends upon the degree of performance required. For a simple oscillator a hexode mixer can be used, and the circuit of Fig. 3.12 illustrates a simple commercial type of beat oscillator. The radio-frequency oscillators will be easily distinguished. The outputs from these are fed to the signal grid and modulator grid of the hexode, the relative strength being so adjusted as to give a good waveform for the beat tone. In the anode circuit of the mixer valve is a simple capacitance shunt which presents a low impedance path to the radio-frequency component still left so that it is only the audio-frequency beat tone which is passed out through the output valve.

The coupling between the mixer and the output valve is through a variable potentiometer which acts as a control of output and this particular instrument gives a waveform having less than 3 per cent distortion from 25–12,000 c/s.

For more precise oscillators diode mixing is to be preferred. Here both the signals are fed to a diode rectifier as shown in Fig. 3.13. The outputs from the two oscillators are each fed through resistances P and Q, which in association with the resistance R serve to cut down the voltage by a given amount. The fixed oscillator is arranged to deliver a voltage to the diode much stronger than that of the variable oscillator which therefore merely serves to increase and decrease the amplitude of the combined oscillation by a small amount. Under these conditions the diode operates over a strictly linear portion of its characteristics, and the waveform of the audio-frequency output is particularly pure. In the arrangement shown

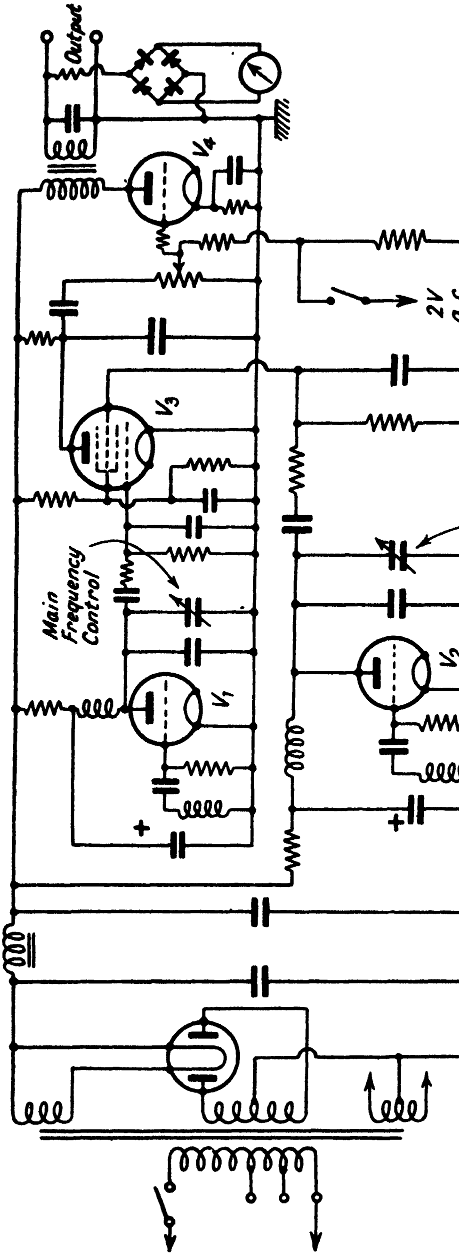


FIG. 3.12. Circuit Diagram of Typical Beat-Frequency Oscillator. (By courtesy Furzehill Laboratories, Ltd.)

a π section filter is inserted following the diode load to remove the radio-frequency component practically completely without having any shunting effect over the audio-frequency range.

This is an improvement over the simple filter of Fig. 3.12 because the audio-frequency output is variable up to quite high audio frequencies and at 10 or 15 kc/s the shunting action of a simple condenser may be quite appreciable so that the output tends to fall off as the frequency rises. Using the circuit of Fig. 3.13, however, the audio-frequency output is practically constant over the entire audio-frequency range.

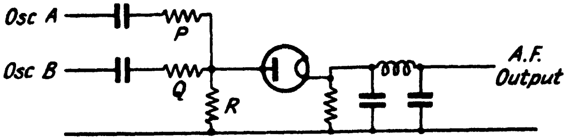


Fig. 3.13. Alternative Method of Mixing to Provide Purer and more Constant Output.

Drift. The tuning condenser of the variable oscillator is calibrated directly in the difference frequency but the setting of this will only be correct provided that when this is at its zero setting the two oscillators are operating at exactly the same frequency. They may be designed to do this but due to minor differences of temperature they will not be exactly the same, and it is necessary therefore to incorporate a small zero-setting condenser which alters the frequency of the "fixed" oscillator by a small amount. In setting up the instrument therefore the main dial is set to zero and this zero-setting control is adjusted until the output falls to zero.

This adjustment will not remain constant indefinitely because as the whole apparatus warms up the fundamental frequencies of the radio oscillators may change very slightly, and this will cause a gradual change in the beat frequency output. This is known as drift, and the aim of the designer is to reduce this drift as far as possible. The extent to which this can be done is a matter very largely of cost, though with good designs a satisfactory drift can be obtained without too great an expense.

The oscillator illustrated in Fig. 3.12, for example, though quite inexpensive, has a drift of only some 5 c/s per hour, which is usually negligible. For certain purposes a drift of this order, however, is too much, and by locating the oscillators in positions where they are not subjected to heat influence, it is possible to reduce the drift to a few cycles per second per day only, which is close enough for quite accurate work. It is usually necessary, however, to allow a period of 30 or 40 minutes for the instrument to warm up before it becomes really stable.

It is often supposed that provided the oscillators drift at the same rate the audio-frequency drift will be zero. This, however, is quite incorrect. Suppose we have two oscillators operating at 100 kc/s and in a given period they each drift to 105 kc/s, the difference frequency will still be zero and the drift therefore will apparently be nothing. Let us suppose, however, that the instrument is set to give 10 kc/s beat tone. The oscillators will then be operating at 100 and 110 kc/s. If the oscillator frequencies now change by 5 per cent as before we shall have frequencies of 105 and 115·5 kc/s, giving a difference frequency of 10·5 kc/s. In other words, the frequency will have drifted by 500 c/s and the drift is, in fact, *the same as the drift of the primary oscillators,* namely 5 per cent.

The only remedy against drift, therefore, is to make sure that the primary oscillators do not change their fundamental frequency appreciably, which can be done by careful design, sometimes assisted by the use of ceramic tuning condensers having a negative temperature co-efficient which causes their capacity to be reduced with temperature rise. As the inductance of the coils increases with temperature these two effects can be made to counteract one another.

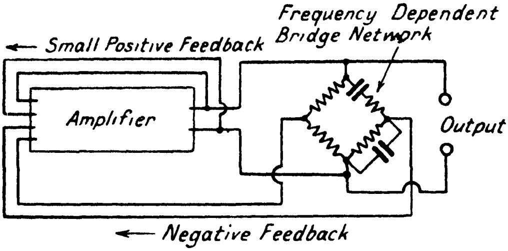


Fig. 3.14. Diagram of Feedback Oscillator.

R-C. Oscillators. Within the last few years there has been some development in resistance-capacitance oscillators. These are of two types. In one, a resistance-coupled amplifier is used in which a phase shift of 60 degrees is introduced at each stage. If three stages are used the total phase shift is 180 degrees, and if this output is fed back to the input in the correct sense continuous oscillation will result. This oscillation will only occur at the frequency at which the total phase shift is 180 degrees, which is a factor determined entirely by the resistances and capacitances in the couplings.

The other type of oscillator is the feedback oscillator in which a resistance-coupled amplifier is built having a fairly high gain which is then reduced to a small value by means of negative feedback. The feedback, however, is applied through a bridge network consisting of resistances and condensers which balance at a particular frequency. At this balance point, therefore, the feedback is zero and the amplifier develops its full gain, while at other frequencies the feedback is operative and the amplifier has very little gain. Thus the arrangement acts as a sharply tuned amplifier despite the fact that there are no conventional tuned circuits in its make-up.

Such amplifiers indeed are often used for analysis of waveforms into their respective components or for other purposes where a sharply tuned amplifier is desirable.

If in addition we apply a small quantity of positive feedback the whole amplifier will oscillate at the frequency to which it is tuned, and this oscillation is of a particularly pure waveform. Moreover, its frequency is entirely controlled by the characteristics of the feedback network. The couplings between the valves do not enter into it and the arrangement is therefore particularly stable. It is quite a simple matter to build an oscillator having a stability of 0·1 per cent and to arrange that it shall hold this calibration over a wide range of operating temperature.

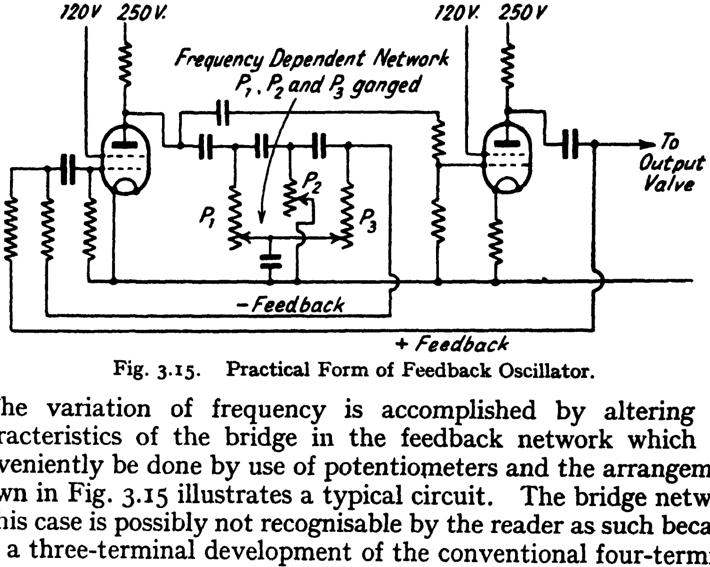


Fig. 3.15. Practical Form of Feedback Oscillator.

The variation of frequency is accomplished by altering the characteristics of the bridge in the feedback network which can conveniently be done by use of potentiometers and the arrangement shown in Fig. 3.15 illustrates a typical circuit. The bridge network in this case is possibly not recognisable by the reader as such because it is a three-terminal development of the conventional four-terminal bridge. It has the advantage that one side of the network can be earthed both on the input and output side, whereas with the arrangement shown in Fig. 3.14 this is not possible so that a transformer is required, which introduces complications. By varying the resistances, which are all assembled together in the form of a ganged potentiometer, a range of 10–1 in frequency can easily be covered, and it is then possible to alter the condensers by means of switches so that multiplying factors are obtained, and in this way an oscillator having a very wide range is obtained, together with the possibility of very fine controls. It has the further advantage that no zero setting is necessary, and the drift is quite negligible.

Fixed-frequency Oscillators. For simple tests a single frequency oscillator may be used. This can easily be constructed by using a conventional circuit of the type shown in Fig. 3.16. The resistance in the anode circuit is adjusted to restrict the amplitude of oscillation so that the valve operates over a linear portion of its characteristic.

If an iron-cored choke is used this should be gapped to a "constant inductance" condition, and the voltage swing kept small. Otherwise the inductance of the choke will vary with the voltage across it which will give rise to a distorted wave.

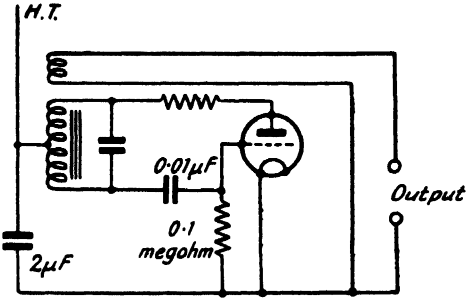


Fig. 3.16. Circuit of Simple Fixed-Frequency Oscillator.

The frequency generated may be estimated from the customary formula $f = 1000/2\pi\sqrt{(LC)}$ where L and C are the inductance in henries and capacitance in microfarads but this formula is not exact because it does not take account of the valve damping. It is near enough for practical purposes.

Some "service" signal generators permit the audio-frequency modulation voltage to be brought out externally, usually through a simple potentiometer, providing a roughly controllable output, though the waveform is usually poor.

A.F. Attenuators. For a.f. measurements it is necessary to be able to control the output from the oscillator. The difficulties, both of attenuation and measurement, are much less than at radio frequencies, and the attenuator network is often a separate unit.

One method is to use a potentiometer system across the output. Low resistances, of a few thousand ohms only, must be used here, as otherwise the self-capacitance of the circuits may introduce errors at the higher frequencies. With this proviso, however, a potentiometer, as shown in Fig. 3.17, may be used, and ratios of several hundreds may be measured quite satisfactorily.

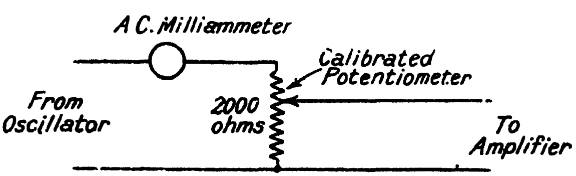


Fig. 3.17. An Alternative System of Measuring Output.

A better method is by the use of attenuating networks. These are arrangements of resistances which have a potentiometer effect, in that the output voltage is a predetermined fraction of the input, but they have the important property that the effective resistance of the whole network *is always the same.* This is important when the oscillator is required to work into a given, fairly low resistance, load, for the arrangement of Fig. 3.17 is only suitable for operating into a high impedance, i.e. for simple voltage measurements.

A simple attenuator is shown in Fig. 3.18. With the switch in position (*a*) the resistance across the terminals *A B* is 600 ohms and the full voltage is applied to the output. In position (*b*) the attenuator section is in circuit and a calculation will show that the output voltage is only one-tenth of the input voltage, but the effective resistance across *A B* is still 600 ohms. Hence the introduction of the attenuator has not affected the constants of the circuit except to reduce the output, and if the current through the circuit is measured by a milliammeter the voltage on the output is quickly and easily determined, being in fact $600 \times I \times k$ millivolts, where I is the current in mA and k is the attenuation factor (equals 0·1 in the case shown).

The attenuation is usually measured in decibels (dB), this being a unit which is proportional to the logarithm of the output relative to a given standard level.[1] If we reduce the output ten times we say it is 10 dB down. If 100 times it is 20 dB down, and so on.

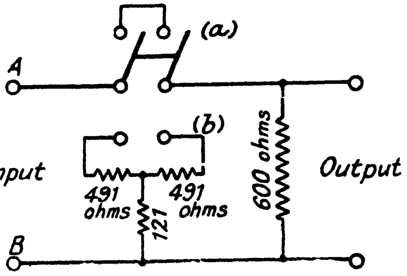


Fig. 3.18. T Section Attenuator.

The decibel is a unit borrowed from telephone practice where it is used for comparing *power.* Being a logarithmic unit the total loss or gain over a number of points is obtained by adding the gains and losses in dB, which is often convenient.

Thus if each stage of a three-stage amplifier shows a loss of 6 dB (about half the normal voltage as explained on the next page) the total loss is 18 dB (8 times). The decibel is also convenient in a.f. work since the ear is more nearly logarithmic than linear in its response. If the power is doubled a certain change in intensity will be noted by the ear. To obtain a similar increase the power must again be doubled. Increasing the power by the same *amount* as before will not double the apparent noise. Moreover, the minimum change which can be detected by the ear is of the order of 1 to 2 dB at normal intensities.

It must always be remembered that the decibel is a power ratio and hence the voltage or current ratio is the square root of this. Thus if the voltage is increased ten times the power will be increased 100 times corresponding to a gain of 20 dB. Similarly a loss of

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[1] If P is the standard output power and P_1 the measured output, then the attenuation is $10 \log_{10} P_1/P$ decibels.

10 dB, representing a power loss of 10 times, is equivalent to a voltage reduction of $\sqrt{10}=3{\cdot}16$ times.

Table IV gives the ratios of power and current in terms of dB. Intermediate values are obtained by multiplying the ratios quoted. Thus 18 dB corresponds to $10\times6{\cdot}31=63{\cdot}1$ times the power or $3{\cdot}162\times2{\cdot}512=7{\cdot}93=\sqrt{63{\cdot}1}$ times the voltage or current.

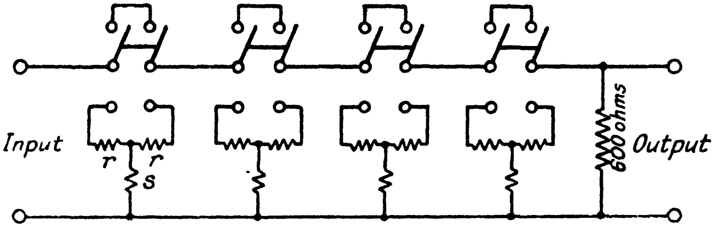

Fig. 3.19. Complete Attenuator Network.

By connecting a number of T-section links in series (as shown in Fig. 3.19) an attenuator may be made having a wide range of control. For instance, if one link attenuates 4 dB and another 10 dB, then if both links are in circuit the attenuation is 14 dB. Table V below gives the values of r and s for a number of attenuation factors, and Fig. 3.19 shows the arrangement of the circuit. By the use of suitable combinations any attenuation from 1 to 40 dB is obtainable. Any of the steps may be omitted if desired.

TABLE IV

CONVERSION TABLE OF dB TO POWER AND VOLTAGE LEVELS

dB	Power ratio	Voltage (or current) ratio
1	1·259	1·122
2	1·585	1·259
3	1·995	1·412
4	2·512	1·585
5	3·162	1·778
6	3·981	1·995
7	5·012	2·239
8	6·310	1·512
9	7·943	2·818
10	10.0	3·162
20	100	10
30	1,000	31·62
40	10,000	100

TABLE V

RESISTANCES FOR T ATTENUATOR (600 OHMS)

Attenuation dB	r	s
1	34·5	5,201
2	68·8	2,583
3	102·6	1,703
4	135·8	1,258
10	311·6	421·6
20	490·9	121·2
30	563·2	37·99
40	588·1	12·00

The accuracy of attenuation depends on the network being correctly terminated by the load for which it was designed. If it is to feed into a high resistance, a load of the correct value must be provided (c.f. the 600 ohm load resistance in Fig. 3.19). If the load itself is of the correct value the artificial load is removed. Unless the correct load is used the attenuation will not be correct, as the reader may check for himself.

The values of r and s may be calculated for other values of load by simple proportion. Thus for a 5,000 ohm load a 10 dB pad would have $r=311{\cdot}6\times 5{,}000/600=2{,}600$ ohms, while S would be 3,510 ohms. For any load R, if the attenuation input volts/output volts $=k$, then

$$r = R\left(\frac{k-1}{k+1}\right) \text{ and } s = R\cdot\left(\frac{2k}{k^2-1}\right)$$

It is possible to arrange a variable section in addition to the steps, by using a tapped input potentiometer of the form shown in Fig. 3.6, and there are attenuators on the market giving continuous variation up to 100 dB which operate with a 20 dB variable section and four fixed steps each of 20 dB.

Output Meters. We now come to a consideration of the indicators used for measuring the voltages developed. For audio-frequency work a rectifier voltmeter is often used. If the waveform is reasonably good this gives quite satisfactory indication of the audio-frequency output and provided it is connected across the circuit at a point where the resistance of the output meter will not seriously affect the result the technique is quite satisfactory. One could, for example, connect an ordinary rectifier voltmeter across the output terminals of the loud speaker transformer and measure the voltage developed here.

If this voltage proves too low for convenience the voltmeter could be connected across the primary side, but in this case it should be isolated from the direct current flowing by introducing a series condenser. The value of this series condenser must be high enough to prevent any undue loss of voltage at the particular frequency in question. Provided the product $RC\omega$ is greater than 10 where R is the resistance of the meter in megohms, C is the capacitance in microfarads and ω is 2π times the frequency, satisfactory readings will be obtained. The development of this expression is detailed in Appendix II.

The use of a meter across the loud speaker suffers from the disadvantage that the loud speaker impedance is not usually accurately known. For any accurate tests, therefore, the output of the receiver should be fed into a known load resistance and the voltage across this resistance (or the current through it) measured with a suitable meter. For the most accurate measurements the latter course is preferably adopted because this can be done with a thermal ammeter which reads the true r.m.s. value and therefore indicates the output irrespective of waveform, whereas as already explained in Chapter I the rectifier voltmeter is liable to error if the waveform is not good.

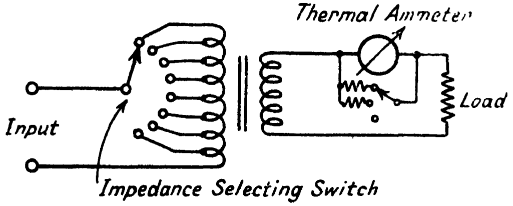

Fig. 3.20. Circuit of Typical Output Power Meter.

It is obviously possible to combine the meter and its load resistance together with a suitable transformer, to provide an instrument which serves at once as a load and as a measuring instrument. Such a device is known as an output meter and it is usually made up with a multi-tapped transformer so that a variety of impedances can be chosen to suit different types of circuit. If, in addition, a multi range meter is used it is possible to read over a wide range of current or voltage. The meter is usually calibrated in terms of output power because since the load resistance is constant we are justified in assuming that the output power is I^2R or V^2/R.

Fig. 3.20 illustrates the circuit of a typical instrument of this type, and output meters can be obtained reading from 1 milliwatt up to 5 or 10 watts. For very sensitive work microwattmeters are in use, although these are usually not quite so accurate because the powers are so small that the power taken by the meter is an appreciable fraction of the whole. This means that a rectifier meter is essential, and as we have seen the rectifier impedance changes with current. If the instruments are used as current meters pure and simple they are quite accurate, but if they are calibrated in watts which must be done on the assumption of a constant impedance, it is clear that some inaccuracies will result. When using any output meter, therefore, it is desirable to know the conditions under which it is calibrated so that if any accurate measurements are being made due allowance can be made.

Microwattmeters, of course, can be made with thermal meters, but these have to be of the vacuo junction type with a galvanometer across the couple so that the set-up is essentially a laboratory arrangement.

Valve Voltmeters. For radio frequency indication and for many audio frequency purposes valve voltmeters are used. These are arrangements consisting of an ordinary valve arranged as a rectifier so that the input voltage is caused to alter the anode current of the valve. There are numerous kinds, each having their own advantages and defects.

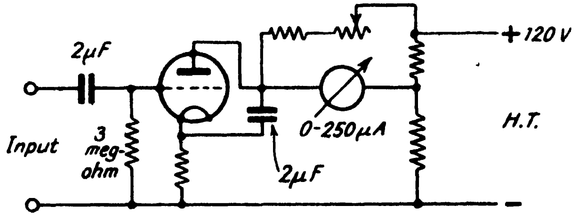

Fig. 3.21. Circuit of "Reflex" Valve Voltmeter.

A convenient all round instrument is that shown in Fig. 3.21. This is an anode bend rectifier with a percentage of negative feedback provided by incorporating a resistance in the cathode lead and omitting the customary by-pass condenser. Under these conditions variations in the valve or the h.t. volts have little effect on the calibration.

In operation the circuit is adjusted so that normally the anode current is quite small. The application of a signal causes the anode current to increase in accordance with the customary anode bend rectifier action, and the extent of this increase can be recorded on the scale of the meter in terms of the actual input voltage necessary. Because of the negative feedback the scale shape is linear over the greater part of its range, and provided the time constant of the input circuit is suitably designed, this form of meter tends to read the average value of the applied voltage, which, as mentioned in Chapter I, is preferable to the peak value, particularly with distorted waveform. Meters of this kind are quite satisfactory for full scale deflection of about 5 volts and upwards, the lowest convenient reading being of the order of half a volt. They are independent of frequency up to 40 or 50 Mc/s and can be used satisfactorily down to 25 c/s or even less provided suitable care is taken with the time constants in the circuit as explained in Appendix I.

In order that the greatest use may be made of the meter it is customary to back off the small permanent current which flows in at zero signal and provision for doing this is shown in the circuit of Fig. 3.21, where a small excess voltage is provided through an adjustable potentiometer which is brought out to the panel of the instrument and set so that the pointer is at zero with no signal applied.

Another type of meter is illustrated in Fig. 3.22. This is the slide back voltmeter which has the merit that it does not need an expensive meter. The valve is adjusted so that the meter reads to a given small current with zero signal. The application of voltage across the input terminals will cause the anode current to increase, but it is then reduced to its original value by applying negative voltage to the grid by means of the potentiometer shown. When the anode current has been restored to its former value the negative grid voltage added must be equal to the peak value of the applied signal. The potentiometer *P* can be calibrated in volts and thus made direct reading while to allow for more accurate tests it is always possible to measure the d.c. voltage developed by the potentiometer at any setting.

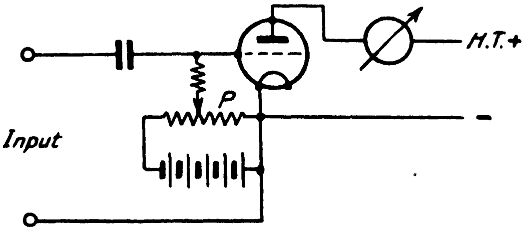

Fig. 3.22. Diagram of Slide Back Voltmeter.

This form of meter has the disadvantage that its setting is a little indefinite since it is not easy to be sure of the point at which the anode current is the same as it was with zero signal. It also reads peak voltage which may not be satisfactory for the particular test in question.

Diode Voltmeter. A form of valve voltmeter rather more sensitive than the Fig. 3.22 type is deliberately intended to read the peak voltage. This type of instrument was originally made up as a cumulative grid rectifier but in its more modern form it is usually constructed up as shown in Fig. 3.23, where a diode rectifier is followed by a valve acting as a d.c. amplifier. This arrangement enables the amplifier valve to be provided with some measure of negative feedback, thus again rendering the calibration substantially independent of valve or battery voltage changes.

This form of meter is often made up with the diode housed in a small probe on the end of a flexible cable. After having passed through the diode the high frequency current, of course, is finished with and the rest of the circuit is concerned with d.c. current only. It is therefore quite feasible for the connections between the diode and the rest of the equipment to be quite long without introducing any inaccuracies, while the diode can then be connected quite close to the point at which the measurement is required, so reducing any errors due to leads. Since at frequencies of 50 Mc/s and over even a few inches of lead may introduce serious error, this technique is particularly convenient.

This type of meter can be made up to give a full scale deflection with as little as 1 volt, while by suitably altering the resistances in the cathode lead, multiplying factors of 10 and 100 are easily obtained. The instrument of Fig. 3.23 is arranged to pass an anode current of several milliamps with zero signal, the anode current being reduced as the signal increases. This gives an improved

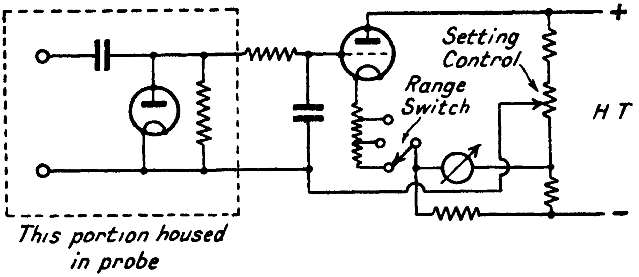

Fig. 3.23. Circuit of Diode Voltmeter.

sensitivity, the "zero" setting being adjusted by altering the steady d.c. voltage applied to the grid.

This meter again has the disadvantage that it tends to read peak than r.m.s. value, although it is usually calibrated in r.m.s. values.

It is possible by altering the circuit arrangement to make the reading approximate to the average value, and in general a meter of this type is always to be preferred unless one is specifically interested in peak voltages.

There are occasions where a peak indication is most helpful. For this purpose a diode meter is excellent, but in this case the input time constant should be so arranged that the time taken for the charge to leak away from the condenser to any appreciable extent is many hundreds of times greater than the time of one oscillation. This is very easily capable of calculation, the data necessary being found in Appendix I.

Since the diode voltmeter consists of a diode followed by a d.c. amplifier-indicator, it can obviously be used for d.c. voltage measurements, and in many instruments provision is made for this facility. The diode voltmeter used in this way has the advantage of a very high input impedance (50 to 100 megohms), so that it exercises a completely negligible influence on the circuit under test.

Amplifier Voltmeters. The use of negative feedback permits valve voltmeters to be made up incorporating amplifiers of various types. Normally this would be unsatisfactory because the gain of the amplifier would be subject to variation with changes in h.t. voltage, valve ageing and circuit changes generally.

If an amplifier is constructed, however, with a substantial negative feedback, meaning that part of the output voltage is fed back to the input in such a direction as to reduce the total gain, the overall amplification is proportional almost entirely on the feedback factor (i.e. the proportion of output voltage fed back to the input) and is *independent of the valves and coupling circuits in the amplifier itself.*

This technique is being used considerably in modern communications design. It has obvious applications to meter design since it makes it possible to design amplifiers of really stable characteristics. A typical "feedback" voltmeter on the market gives a good reading with 1 millivolt and has five ranges corresponding to full scale deflections of ·01, 0·1, 1, 10 and 100 volts. It is accurate over a range of 10 c/s to 500 kc/s. Similar technique can be applied at radio frequencies enabling fractions of a volt to be read at frequencies as high as 50 Mc/s.

These instruments rank as laboratory equipment rather than service instruments, but for the test laboratory they are of great utility and are likely to be used to an increasing extent.

Combination Instruments. For the convenience of the service engineer several manufacturers market instruments which combine the functions of several individual instruments. Messrs. Taylor Electrical Instruments, for example, market a diode voltmeter arranged to measure d.c. or a.c. voltage and current (this latter quantity being measured by passing the current through a small resistance and noting the voltage drop across it), while by changing the circuiting by means of a switch the indicating meter itself can be used as a normal universal meter reading voltage, current and resistance.

A similar instrument known as the Avo Electronic Testmeter is marketed by the Automatic Coil Winder and Equipment Co. This is a combined valve voltmeter and universal meter which, in addition to the normal current, voltage and resistance measurements, is provided with a scale whereby the current through a condenser is calibrated in terms of the capacitance.

CHAPTER IV

AUDIO-FREQUENCY TESTS

HAVING discussed general methods of testing it now remains to investigate the various portions of the receiver in greater detail. This chapter is concerned with the various tests which may be necessary upon audio-frequency apparatus. The audio-frequency portion of the receiver commences at the detector stage, and may consist of any number of stages, although in ordinary practice one or two stages are sufficient. The input voltage at which the modern detector valve functions is such that one stage of amplification following will usually give adequate loud speaker strength, even for large power outputs, and many sets use a diode detector feeding direct into a high-sensitivity output valve.

The detector stage has to handle both radio- and audio-frequency currents and can develop faults from a failure to perform either duty successfully. With some sets gramophone reproduction is provided for by using the detector valve as the first low-frequency valve, thus obtaining a two valve arrangement, and amplifiers having a larger number of stages than this are only occasionally encountered. There is, of course, the P.A. (public address) amplifier which may have more stages, particularly when working with a crystal microphone, but the general technique remains the same.

Now the faults which develop in low-frequency amplifiers may be as under:

1. Amplifier refuses to function.
2. Loss of efficiency.
3. Bad quality.
4. Amplifier howls or whistles.

These various cases will be dealt with *seriatim*.

Amplifier Refuses to Function. Where the low-frequency amplifier does not work at all the location of the difficulty is fairly simple. The methods which must be adopted are those discussed in Chapter I. Some progressive indication of the soundness of the circuit must be obtained working from the output end of the set towards the input end.

Some part of the circuit will fail to give the expected response and it may then be examined in detail, checking the voltages, anode current, grid bias, continuity of grid circuit, etc., until the fault is located. As an example of the technique let us consider a simple circuit of the type shown in Fig 4.1. We will assume that on connecting up the h.t. plug to the battery a click is heard in the loud speaker. We can then assume the output valve to be in order, as any rate as far as its anode circuit is concerned. Now if we touch the grid of V_2 with the finger a clicking noise should be heard, probably accompanied by a small amount of hum picked up from any electric-lighting mains in the vicinity. We will suppose, however, that on making this test nothing happens. The first step is to check the anode current of V_2. If it is very small the valve is either over-biased or defective. If it is much too large the valve may be "soft" as explained in Chapter XI, or it may be underbiased. The grid bias cannot be checked by connecting the voltmeter across grid and filament because the current taken by the voltmeter, even though small, would cause so much voltage drop on

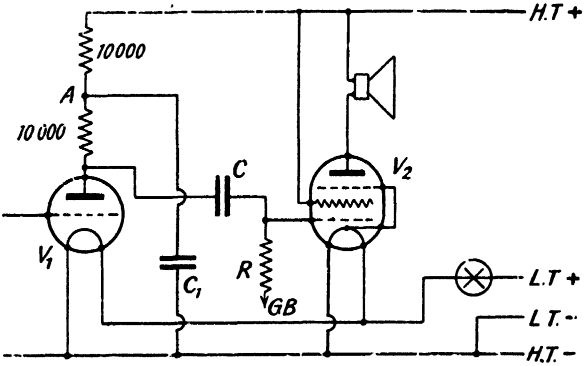

Fig. 4.1. The Simple Battery Circuit of Fig. 1.1 is here Reproduced for Convenience.

the grid leak that the reading obtained would be quite inaccurate—if, indeed, any satisfactory reading were obtained at all.

It would be possible to make suitable allowance but this is unnecessary, since unless we have reason to suspect the valve of softness, we can assume that the voltage actually on the grid is altogether too small. Now, it is possible for such an effect to be produced if the coupling condenser *C* is leaking, for then a small current will pass from the anode of the preceding valve through the leak in the condenser and through the grid leak *R* to earth, developing a positive voltage on the grid which will partially or completely offset the negative voltage provided by the grid bias battery. It is not necessary for this leak to be very large in order to produce quite considerable positive voltage. If the grid leak is 1 megohm and the leak across the condenser is 10 megohms, then we shall have 1/11th of the anode voltage applied to the grid. The anode voltage of V_1 would be of the order of 40, which would apply nearly 4 volts positive on the grid, so that if the grid bias tapping is 4½ volts negative, the effective negative bias is only ½ volt.

One way of checking this would be to short-circuit the grid leak *R*. This would allow the negative grid bias from the battery still to be applied to the grid, but it would prevent the leakage current through C from developing any voltage, and if by doing this we find that the anode current drops there is a clear indication of a leak on the condenser.

To make quite certain the next move would be to disconnect one side of the condenser C. This again would remove the leak and the anode current of the last valve should drop to its normal value.

Defective Anode Circuit. Let us next assume that the last valve is in order, but that the preceding valve seems dead. There are various rough ways in which this could be checked, such as touching the grid of the first valve with the finger which should produce quite an appreciable click in the loud speaker, or removing the valve altogether which should again produce a click. If this indication is not obtained the voltmeter would again be brought into use and the voltage measured on the anode of the valve V_1. We find, say, that this is zero.

Now this can be due to two causes. The anode resistance or the de-coupling resistance may be broken and we can easily check this by measuring the voltage from the h.t. point backwards. Full h.t. would be developed on the h.t. line. What of the voltage at the point A? If the de-coupling resistance is broken there will be no voltage at this point. If the anode resistance is broken there would be full voltage at this point.[1] A voltmeter test will immediately determine which of these two possibilities applies.

If the anode resistor is broken then the remedy is obvious. If necessary, the resistance itself may be checked with an ohmmeter, which may be done without disconnecting provided the h.t. battery is disconnected. On the other hand, if the voltage at the point A is zero it indicates the possibility that the de-coupling resistance is broken. This point again may be checked with an ohmmeter, and if this is found to be a correct diagnosis the resistance may be replaced.

There is still another possibility, however. We may find that the resistance is quite correct and yet the voltage at the point A is still zero. There is only one answer to this problem, namely, that the de-coupling condenser C_1 is short-circuited so that in effect the de-coupling resistance is being connected across the full h.t. battery. It may be remarked that if this fault did occur, it is probable that the resistance would get hot, for it is passing something like three times its proper current, therefore, dissipating nearly ten times its normal watts. It is also interesting to note that this fault would be shown up at once by measuring the voltage drop across the resistance instead of the voltage between the point A and earth. A voltmeter so connected would have indicated the full h.t. voltage across the resistance which is obviously incorrect, whereas, if there had been a break in the resistance and de-coupling condenser C_1

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[1] Apart from a small voltage drop due to the meter current.

was quite sound, no voltage at all would have been shown between the point *A* and the h.t. line.

It will be clear that failure to function can very often be located by the intelligent application of voltage tests, backed up where necessary by a current measurement. It is not necessary or even desirable to consider a large number of circuits with their possible faults for enough has been said to indicate the method, which is the main consideration.

Use of Oscillator. There are a few faults which will not be shown up by a voltage or current test such as, for example, a broken coupling condenser. A defective component here will not affect the current or voltage distribution in the circuit, but it will, nevertheless, prevent any signals from getting through except perhaps the highest frequencies, so that there may be a very faint squeaking noise from the loud speaker, very much weaker than it should be and containing no low or medium frequencies at all.

The experienced tester, hearing such a noise, would suspect a broken coupling condenser, but the matter can be put beyond any doubt if a suitable source of low frequency is available. Most modulated test oscillators contain provision for using the modulation only, without the radio-frequency signal, whereby a musical tone may be injected into the low-frequency amplifier at suitable points. By connecting such an oscillator first to the grid of the output valve and then to the anode of the preceding valve, the grid of the preceding valve and so on back to the front of the amplifier, the fault is quickly located. For example, in the case just considered satisfactory signal should be obtained with the oscillator connected to the grid of V_2, whereas, if the connection is transferred to the anode of the V_1 no signals would be heard, indicating a complete break in the condenser *C*.

Loss of Efficiency. Some form of artificial signal is almost essential when dealing with the second type of fault in which the amplifier functions but does not give its proper performance. The value of the test depends upon the accuracy with which the results need to be known and the quality of the apparatus available. Given an audio-frequency oscillator, attenuator and valve voltmeter accurate tests can be made. In the absence of one or more of these instruments the accuracy of the tests suffers but it is possible to obtain indications which will point the way to any defects.

In the present section, therefore, we shall assume the existence of the necessary equipment and outline the methods adopted.

The basis of efficiency tests is the measurement of the gain or amplification either of the complete amplifier or of individual stages. The procedure is to introduce a known voltage across the input and to measure the output. The amplification or gain is then obtained by dividing the output by the input.

Measurement of the output voltage may be made by means of a valve voltmeter of the type discussed in Chapter III. The use of such an instrument enables us to make measurements on any amplifier stage because a valve voltmeter nearly always has a high input resistance so that it may be connected across any part of the circuit without affecting the circuit arrangements. This is a most important feature in any measurement and it is always necessary to make sure that in the process of measurement the circuit has not been disturbed by an amount which will invalidate the result.

In the case of a valve voltmeter the disturbance introduced is mainly on account of the additional capacitance which is connected across the circuit due to the leads and the valve itself. As already explained, some types of valve voltmeter are fitted with a probe which houses a small diode and this probe can be located quite close to the circuit under test, so that the additional capacitance introduced is restricted to the minimum. Capacitive effects in any case are only likely to be troublesome at high frequencies and usually the effect does not cause any difficulty during audio-frequency tests.

If the valve voltmeter is not of the probe type it should be located reasonably close to the equipment so that the connecting leads are short and of course these leads must be kept away from the input to the amplifier as otherwise feedback may occur which may either decrease or increase the amplification and in serious cases cause self-oscillation, particularly with a high gain amplifier.

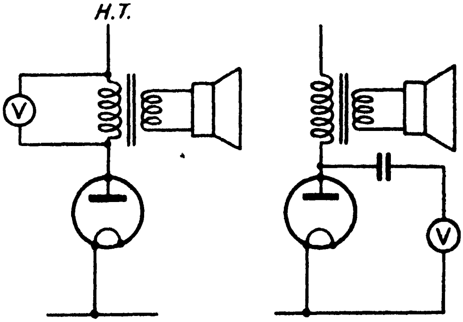

Fig. 4.2. Alternative Methods of Measuring Output Voltage.

The alternative method is to use an output meter in place of the loud speaker. This method has the limitation that the output meter must always stay in this one place. The output meter, having a low resistance of a few thousand ohms (since it is designed to act as a load in place of the loud speaker) cannot be connected across other parts of the circuit without seriously disturbing the arrangement. With an output meter therefore it is necessary to measure first of all the gain of the output stage and then to follow on by measuring the gain of the preceding stage plus the output stage and so on—i.e. measuring the whole gain of the amplifier which will be slightly more difficult because the input will need to be cut down to a lower value and as was emphasised in Chapter II any measurements involving small input voltages are attended by difficulties because of the ease with which the results can be invalidated due to stray coupling.

If neither a valve voltmeter nor an output meter are available it is possible to use an ordinary a.c. voltmeter to measure the voltage developed across the loud speaker itself. Without a knowledge of the effective impedance of the loud speaker network this method can only serve as an indication. From a knowledge of the type of output valve it is possible to find the recommended output load from the valve makers' figures, and one can assume that the receiver has been designed accordingly. Knowing this figure and being able to measure the voltage across the input to the loud speaker transformer one can then calculate the power being developed from the expression: Power $= W = V^2/R$ watts, where V is the r.m.s. voltage across the load R.

If one is only concerned with the gain, of course, the load impedance does not matter. In any case in measuring the voltage across the primary of the loud speaker transformer it should be remembered that this point is at a fairly high d.c. potential. It is possible to connect the a.c. meter across the transformer primary itself, as shown in Fig. 4.2, because the d.c. volts drop across the transformer primary is comparatively small, usually of the order of 20 volts, and if one is reading a voltage of the order of 100 volts a.c. (r.m.s.) this small superposed d.c. will have little effect on the readings.

It is, of course, possible to filter out the d.c. component by connecting the meter through a large condenser. This condenser must be large enough to avoid causing any appreciable voltage drop at the frequency in question. The voltage developed will divide itself part across the condenser and part across the meter, and it is a simple matter to calculate the size of condenser needed so that the drop on the condenser shall be negligible. This calculation is outlined in Appendix II, but it may be taken that if R is the resistance of the voltmeter in megohms and f is the frequency of the measurement, no serious error will be introduced provided that the capacitance exceeds $1/fR$ microfarads.

Order of Test Voltage. When making gain measurements it is essential that the voltages used should be of the same order as those which will be encountered under ordinary operating conditions because the circuit will have been designed for such voltages. If larger voltages are used there will be a danger of overloading which will give misleading results. Similarly if smaller voltages are employed the result can also be deceptive because the valve may be in a condition in which it overloads with normal operating conditions whereas it behaves satisfactorily to small signals.

A knowledge of the correct operating conditions can be obtained from examination of the circuit. The output valve, for example, should be operating under a certain specified grid bias (and as part of the routine this grid bias will be checked to make sure that it is of the right order). Now this grid bias with any class A valve should be slightly greater than the peak value of the maximum input signal. The maximum peak input signal on the preceding valve must be equal to this value divided by the gain of that valve and the expected gain can easily be calculated from the circuit constants.

If the preceding valve is a resistance-coupled triode then the gain is given by $A = \frac{\mu R}{R + r}$ where μ = amplification factor.
r = a.c. resistance of valve.
R = external anode resistance.

The expression may be written in the form $A = g. \ Rr/(R + r)$, where g is the mutual conductance or slope of the valve and r and R are as before. If the valve is a pentode so that r is several times greater than R, the expression becomes simply $A = gR$.

In the case of a transformer coupling the preceding valve will almost certainly be a triode in which case the transformer should have been designed so that it presents a large impedance thereby obtaining practically the full amplification factor from the valve at medium frequencies. As a rough estimate therefore the gain at medium frequencies should be $\mu \, n$, where n is the step-up ratio. At low frequencies the primary impedance will fall off causing reduction in gain, while a similar effect occurs at high frequencies due to the shunting action of the self-capacitance. This question is discussed further later in the chapter.

Precautions in checking gain. The input voltage should be obtained from a suitable oscillator which may either be a beat-frequency or a resistance-capacitance oscillator of the type already described, or it may be the modulation voltage from a signal generator, which is often brought out as a separate supply in service instruments, as previously mentioned. In any case it is desirable that the voltage should be pure and if the output from a signal generator is being used this point is worth checking.

The need for this proviso will be obvious if any check is being made on the quality of reproduction which is discussed in the next section, but the need is not so apparent when considering gain measurements. It is important, however, for two reasons. Firstly, that the usual type of indicator used is sensitive to waveform and will give false indications with a distorted waveform particularly if this happens to be peaky. Secondly, a distorted waveform may produce overloading in the valves during certain parts of the cycle with the result that distortion is produced and the output waveform will be different from the input, and this again will cause a discrepancy between the expected output reading and the actual. The extent to which these factors are of importance again depends upon the accuracy of the information sought and for rough checks of performance these points can be ignored.

The output from the oscillator should be known and may be determined either by its own output indicator if such is incorporated or by using an external meter for the purpose. Certain types of test do not involve accurate knowledge of the input voltage but depend instead upon an accurate setting of an attenuator.

The construction of attenuators has already been mentioned.

For rough purposes it is possible simply to vary the output from the oscillator by means of its own control, but for the best results, particularly with scientific testing, the oscillator should be adjusted to some figure near its full load value and the output reduced as required by means of external attenuators. Indeed, the technique of measuring gain if often based on this assumption, the arrangement being to apply voltage to the input of the last stage and to measure the output voltage across the loud speaker. The input is then removed on stage farther back and the attenuator setting is adjusted (in such a direction as to decrease the output) until the output indicator reads the same as before. The difference in the two settings of the attenuator then gives a direct measure of the stage gain. This arrangement has the advantage that the input voltage at each point is of the right order, while in addition it is not necessary to know accurately what the output voltage is since the indicator is adjusted to the same value each time.

If a proper attenuator is not available a calibrated potentiometer may be used in many instances and this often proves quite a satisfactory procedure. Care should, of course, be taken to ensure that the manner in which the input is introduced into the stage does not upset the circuit arrangements. Generally speaking the input may be connected to the input of the appropriate valve through a small condenser of say 0·1μF, while the earth return is connected to the earth line of the receiver or the amplifier. Except in cases where one is particularly interested in the gain at low or high frequencies the test should be made at a medium frequency between 500 and 1000 c/s. because at such frequencies the constants of the circuit are least likely to introduce secondary effects. At low frequencies, of course, the time constant of the coupling has to be considered, and in particular that of the input from the oscillator itself. If there is a low value of leak between grid and ground of the valve under test a condenser of 0·1μF will certainly be too small and the voltage actually reaching the grid will not be the voltage developed by the oscillator. At high frequencies losses may occur due to the stray capacitances, while any feedback troubles are likely to be accentuated. These effects are discussed more fully in the next section, but it will be clear that for general gain measurements a medium frequency is preferred.

Low Gain. Let us now consider the case when the amplification is found to be below expectation. This fault may be due to one of three causes:

(1) Valve operating under incorrect conditions.

(2) Circuit values faulty. This must also include the possibility of the valve itself being defective.
(3) Feedback.

The circuit operating conditions may be checked by voltage tests as already described. After a little experience one gets to know the typical conditions for various classes of valve, but in any case of doubt it is a simple matter to refer to the figures supplied by the valve makers. These figures contain the normal anode current and grid bias for the specified values of h.t. voltage.

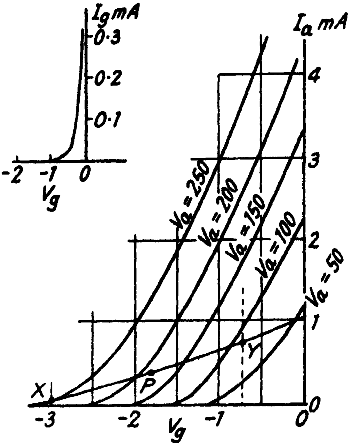

Fig. 4.3. Showing how the Working Characteristic of a Valve Differs from the Static Curves.

It should be remembered that with a circuit having a resistance in the anode circuit voltage on the anode of the valve itself will be considerably less than the full h.t. voltage, and this must be allowed for in deciding whether the valve is operating correctly.

Fig. 4.3 illustrates the ordinary grid voltage-anode current characteristics for a typical triode. This is rated at two volts bias with 1 mA anode current at 250 volts. If the anode circuit, however, contains a resistance, the voltage drop on this, due to the anode current, results in the actual voltage on the anode being reduced. A 200,000 ohm resistance for example, would drop 200 volts at 1mA leaving only 50 volts available at the anode, which condition will be seen, from Fig. 4.3, to correspond to only 0·1 volts grid bias.

With any larger value of bias the anode current will have to be less and in fact the circuit will automatically adjust itself until a suitable condition obtains.

Operating characteristics. The actual characteristics over which the valve operates under working conditions, therefore, are not the same as the static characteristics of Fig. 4.3. Any change in anode current causes a change in the voltage drop on the anode circuit and hence alters the voltage on the anode of the valve itself. Hence the valve is continually changing its working point over the operating cycle.

Let us consider the operating characteristic for the valve of Fig. 4.3, with a 200,000 ohm anode load. With one milliamp flowing the drop on the anode resistor will be 200 volts, leaving 50 only on the anode. The working point therefore will be the point at which the 50 volt static characteristic cuts the one milliamp line. If the anode current falls to 0·5 milliamps the voltage drop will be only 100 leaving 150 on the valve, and the operating point will be where the 150 volt characteristic cuts the 0·5 milliamp line. We can obtain similar points for other values of current, and so plot the *dynamic characteristic* of the valve for the given load which is indicated by the heavy line in Fig. 4.3.

It will be noted that this characteristic is appreciably straighter than the static characteristics in this region, showing that reasonably distortionless amplification can be obtained with a suitable anode load even in regions where the static characteristic appears at first sight to be quite unsuitable.

It may be noted in passing that when obtaining a characteristic in this manner the effect of the cathode resistor must be ignored. The function of the cathode resistor is to provide a fixed bias for steady conditions, and the valve actually operates about this mean value. Across the cathode resistor we connect a by-pass condenser which is designed to have a negligible impedance at the operating frequency so that changes in anode current do not produce any changes in the grid bias. In the case just considered it will be seen that we can operate effectively over the portion XY of the dynamic characteristic. We should not carry the grid swing less negative than about 0·7 volts because here grid current commences to flow with increasing rapidity as is shown on the grid current characteristic, and this means that the input resistance of the valve begins to fall off and exercise a shunting effect on the preceding stage, reducingthe amplification at the peaks of the wave and therefore causing distortion.

We should therefore restrict our operating portion over the region between Y where the grid current starts and X where the anode current is nearly cut off. The steady operating condition will be midway between these points as at P which will be seen to correspond to 180 volts h.t. and 1·8 volts grid bias, the anode current being 0·35 milliamps. This current flowing through 200,000 ohms will drop 70 volts which, subtracted from 250 gives us 180 as just mentioned, while the cathode resistor should be chosen to give 1·8 volts grid bias with 0·35 milliamps flowing, which calculation shows to be 515 ohms.

Around this point we shall be able to swing ± 1·15 volts on the grid without serious distortion. The corresponding change in anode voltage will be from 90 to 250, i.e. 160 volts, so that the stage gain would be 160/2·3 or 69·5.

It should be noted that all these figures are peak to peak figures. The voltages indicated by an r.m.s. meter would be $1/2\sqrt{2}$ times the peak values so that the r.m.s. output voltage is 56·5 and the input voltage 0·81.

A similar procedure can be adopted when the anode load is an impedance, e.g. a transformer, but in such cases it is more convenient to use the method discussed on p. 67.

Incorrect Values. The stage cannot develop correct gain if the component values are incorrect or if a valve is defective. Methods of checking components are discussed in Chapter XI, a section of which is devoted to valve tests.

Obvious errors in components will be shown up by the routine tests already described. An incorrect value of anode or cathode resistance in Fig. 4.4, for example, would result in incorrect voltage distribution. But there are other less obvious faults. The anode circuit, for example, consists of R_a with CR_g in parallel. At any except the lowest frequencies the impedance of the condenser C is negligible so that R_a and R_g are effectively in parallel. Now if R_g happens to have been made one-tenth of its correct value due to a mistaken reading of the colour code, for example, it is likely to be of the same order as or even less the anode resistance R_a so that the effective anode load will only be only a fraction of its supposed value and the gain will be reduced in consequence. Ordinary voltage tests will not disclose a fault such as this.

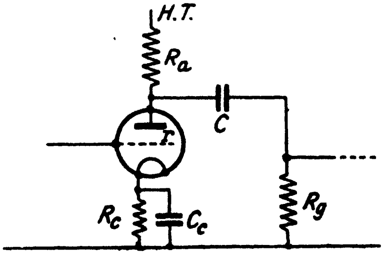

Fig. 4.4. Resistance-coupled Circuit.

At the low frequencies the condenser C has not a negligible impedance and the voltage developed at the anode will be divided and only a portion will be developed across R_g and transferred to the next valve. The actual proportion is easily calculable (see Appendix II) but it will be clear that if the condenser has too small a value then it will begin to exercise an influence on the stage gain at a much higher frequency than the designer intended. Hence if the circuit works well at high frequencies but very badly at low frequencies this is one of the faults to suspect. It is even possible for the circuit to work with a broken coupling condenser because the stray capacitances will transfer sufficient voltage to give some response at the higher frequencies (though only a fraction of the theoretical value).

Another source of low gain is to be found in inadequate by-passing of the cathode resistor R_c. If the valve is to work in the manner just described the impedance between cathode and ground should be negligibly small and the cathode condenser therefore should be large enough to present a negligible reactance at the lowest frequency which the circuit is called upon to handle. With audio-frequency amplifiers this condenser is usually of the order of 50μF for which purpose a small tubular electrolytic condenser is customarily employed.

If this condenser is too small or is broken, negative feedback takes place. The variations in anode current produced by the signal set up voltages across the cathode resistor and a little thought shows that these are in the direction to oppose the input signal. For example, if the voltage on the grid is increased the anode current increases and therefore more voltage is developed across R_c. The voltage between grid and cathode, which is the effective input to the valve, is the difference between the applied signal and the voltage drop across the cathode impedance and is therefore less than the full amount. If the cathode impedance is appreciable this reduction in effective voltage may be considerable and in consequence the output voltage developed is reduced in the same proportion so that the stage exhibits a low gain. The calculation of the extent to which the gain is reduced is discussed more fully in Appendix III.

The effect is frequency dependent in so far as the shunting action of the cathode by-pass condenser becomes less effective as the frequency is reduced.

Hence again we find that an insufficiently large value here will cause the response to be reasonable at medium frequencies and gradually fall off as the frequency is reduced. If the condenser is completely broken the gain even at medium frequencies will be substantially less than it should be. The figures in Table VI will be found useful.

TABLE VI

REACTANCE OF CONDENSERS

Capacitance (μF)	Frequency c/s 50	100	200
0·1	32,000	16,000	8,000
1	3,200	1,600	800
2	1,600	800	400
4	800	400	200
25	140	70	35
50	70	35	17·5

It does not follow that this cathode by-pass condenser must be large. Sometimes negative feedback is deliberately introduced. This may be done because an amplifier embodying such feedback has appreciably better characteristics than a normal amplifier without feedback. In such a circuit, however, it will usually be found that either the cathode by-pass condenser has been entirely omitted or that there is some evidence in the circuit of the introduction of negative feedback as for example in the circuit of Fig. 4.5. Here a small portion of the output voltage is deliberately fed back into the cathode circuit of the last valve but one. It happens that in this circuit, which is part of a beat-frequency oscillator circuit, the output voltage tends to fall as the frequency increases. It is desirable therefore that the feedback should not be constant, but should decrease as the frequency rises and the particular combination of values compensates matters in such a way as to give a substantially constant output. The use of a relatively small cathode by-pass condenser is thus entirely justified in this instance, but it is clear from an examination of the circuit that negative feedback is being deliberately used.

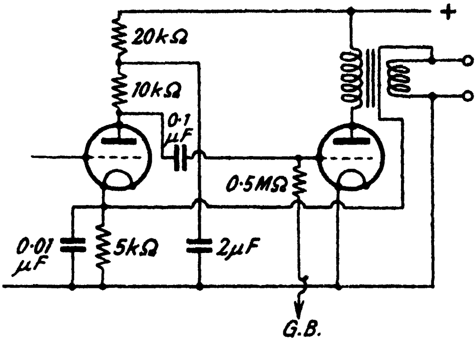

Fig. 4.5. Circuit using Negative Feedback to Improve the Performance.

Push-pull Stages. Another example of a smaller value of by-pass-condenser is to be found in push-pull stages as shown in Fig. 4.6. Here we have a form of push-pull circuit often used in which the second valve of the pair is fed from the anode of the first valve through a step down potentiometer *P*.1, *P*.2. The ratio of *P*.2 to the total resistance *P*.1 + *P*.2 is chosen to be equal to the gain of the valve *V*.2 so that the anode of *V*.2 develops the same voltage as the anode of *V*.1, but in opposite phase.

Now a push-pull arrangement, whether it is fed in this particular manner or whether more conventionally from a split input transformer or from some other form of phase reversing circuit, is characterised by the fact that an increase in the anode current of one valve should be accompanied by an exactly opposite decrease in the anode current of the second valve. Consequently the total current flowing through the cathode resistor *R* should remain constant. It thus provides the necessary steady bias, but since the current does not change there is no fluctuation of this voltage, and hence no negative feedback. Actually the valves in the pair are seldom so accurately matched as to attain this constancy, so that a small by-pass condenser is usually fitted, but it can be considerably smaller than would be necessary with a normal single stage.

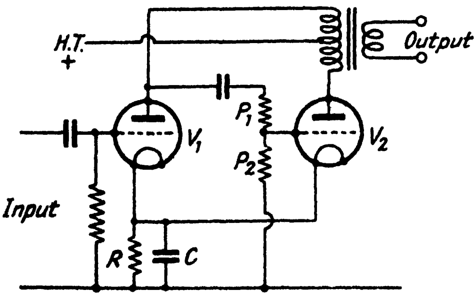

Fig. 4.6. Paraphase Push-pull Circuit.

The testing of a circuit, such as Fig. 4.6, is a matter requiring a little care because the two valves are interdependent. Fig. 4.7 shows a conventional push-pull arrangement. Here it would be possible to measure the anode current of each valve in turn, both under static and operating conditions. The currents should be equal and they should not change appreciably with a signal applied to the input (unless the circuit is operating in class B fashion, which will be considered later). It is not difficult to determine whether the conditions are correct, because one valve may be completely removed without affecting the operation of the other.

If the two valves have a common cathode resistor, however, as in Fig. 4.6, this no longer applies, and it is a good plan if any difficulty is experienced with a push-pull stage having common cathodes to separate the cathodes and connect in temporarily a suitable cathode resistor by-passed with a suitable condenser on each valve. The value of resistor chosen will, of course, have to be twice what it would be if the cathodes were commoned, because it now only carries the current of one valve and not both. The current through it is therefore halved, and so in order to develop the same bias voltage the resistance value must be doubled.

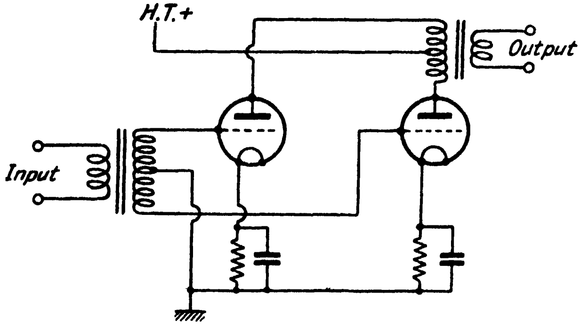

Fig. 4.7. Conventional Push-pull Arrangement.

The adjustment of the paraphase potentiometer in Fig. 4.6 is also quite difficult unless the cathodes are split first of all, and if there is any reason to suspect that one valve is doing more than the other—due to the fact that its anode gets hot perhaps, or possibly due to some distortion shown up by an oscillograph—the circuit should be split so that each valve works independently.

Class B Operation. Most push-pull output circuits in power amplifiers operate on a Class B basis with or without positive drive. The arrangements here are similar to those of Fig. 4.7, with the difference that the bias is increased to reduce the anode current to a small value. Since the bulk of the h.t. current in the amplifier

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[1] A Class A amplifier operates with an anode current equal to approximately half the peak current and the grid swing is limited so that the valve operates symmetrically and hence the mean anode current is steady. If the bias is increased so that the anode current falls to zero during part of the cycle the positive current swing exceeds the negative swing and the mean anode current fluctuates with the signal. This is called Class AB operation. If the process is carried so far as to reduce the standing anode current nearly to zero it becomes Class B operation.

is accounted for in the output stages this means that the power consumption is substantially reduced when the set is idle or working on small outputs and only rises to its maximum value on full output. It will be clear that under such conditions the anode current must fluctuate considerably under conditions of varying input signal, but this does not introduce any difference into the fundamental methods of testing except that it is necessary to ensure that the power unit is capable of supplying the necessary voltage at the rated current. The question of regulation in power units is discussed more fully in Chapter VIII, and it is not necessary to go into the matter more fully here.

With Class B operation the "standing" anode current (with zero signal) is practically zero. The grid swing is then twice what is required for normal push-pull operation, the idea being that instead of having both valves carrying a steady anode current and swinging from nearly zero up to nearly twice the steady current it is possible to obtain the same effect by operating each valve in turn. Both valves are therefore biased to nearly zero current and each one in turn swings up to the same maximum value as it would do if the valve were operating in a Class A condition. The system works quite effectively in practice and the change-over from one valve to the other is quite smooth. The output obtained is four times as much as with Class A operation, but the steady anode current under conditions of zero or small signal is considerably reduced.

Substantially greater outputs, however, can be obtained by driving the valve into the region of positive grid voltage. This results in a considerable increase in peak anode current so that greater power output is obtained. The valve, of course, must be of a type which will stand this momentary increase in the current and during the period when the grid runs positive it draws quite a considerable current itself. It is necessary, therefore, to supply power to the input of the amplifier so that the preceding stage no longer becomes a pure voltage amplifier, but is in effect a small power output stage. It therefore has to be tested as such.

If it is desired to isolate this stage a load equivalent to the load imposed by the grid current should be connected across the terminals of the driver stage. It is not always easy to assess what this load should be, but as a first measure the driver valve itself may be examined and the circuit arranged to give the proper optimum load. The driver stage may then be tested with an artificial load of this value in order to make sure that it is working satisfactorily. Details as to the choice of the correct operating load are in the next section dealing with distortion.

It is necessary to proceed in this matter because unless the output stage is working satisfactorily the conditions may be different from normal. For example, if the anode circuit is disconnected the grid current which flows when the grid is run positive is many times greater than it is under normal operating conditions, so that if the output stage is defective in any way confusing results can easily be obtained.

One method of test is to supply the output stage from a source of power which is easily capable of delivering all the input power necessary, and which has a low internal impedance. Such a source is the mains supply itself, and therefore the mains may be connected through a suitable step-down push-pull transformer to the grid of the output stage and the value of the voltage adjusted to approximate to full load conditions. It will be convenient to consider this point in more detail in the next section, however, after a consideration of load lines in output stages.

Checking Grid Bias. The examination of the grid bias has already been referred to. It is usually sufficient to check the voltage at the battery (or across the bias resistor in a mains set), but it must be remembered that this does not prove that the bias is correct. It may be prevented from reaching the valve by a break in the circuit or a similar fault.

With a transformer coupled stage it is possible to check the voltage actually on the grid (or on the input side of a grid stopper, if any), but with a resistance coupled circuit this is more difficult, because the current taken by the voltmeter will cause considerable voltage drop on the high resistance of the grid leak.

For any reliable test, therefore, a high resistance meter must be used. This will then read $1/n$ of the true voltage where $n = r/(R+r)$, r being the meter resistance and R the grid leak resistance.

Bad Quality. The tracing of distortion in an amplifier is a matter on which a very great deal can be written because of the difficulty of deciding what constitutes satisfactory quality. For the purpose of the present discussion we must assume that if the output waveform is a satisfactory reproduction on an amplified scale of the voltage applied to the input the amplifier is satisfactory.

Actually, very much more than this is involved. For example, the loud speaker itself is a very important link in the chain, but any detailed discussion on this subject must be omitted. Then again the satisfactory reproduction of transient phenomena has an important influence on the relative naturalness of the reproduction. Transient phenomena are impulses which do not repeat themselves regularly and continuously, such as the waveforms originating from the beat of a drum, the clash of cymbals, and in fact a large proportion of the incidental noises which go to make up our normal life. The loud speaker has an even greater part to play in dealing with transient phenomena than with ordinary musical sounds, but it is occasionally desirable to check that the amplifier is satisfactorily reproducing transient impulses and some reference to this will therefore be made.

Again, as has been shown by Harries, inter-modulation is also an important factor. An amplifier may reproduce two separate notes quite satisfactorily, but when it is called upon to reproduce them both together it may be found that one modulates the other so that the output is not a faithful copy of the input. This again is a matter on which we cannot devote any appreciable space, but it may be noted here that the methods of testing proposed for simple examinations can be utilised with a little ingenuity to detect the presence of any such effects as this.

Detector Distortion. A further complication is that bad quality may arise from unsatisfactory operation of the detector stage which, as we have already seen, is called upon to handle both radio-frequency and audio-frequency voltages. Therefore it is desirable to discriminate at an early stage between distortion produced by the amplifier proper and distortion arising from incorrect detector performance. The detector stage is considered in some detail in the next section, and the present remarks therefore must be taken as applying to the amplifier itself.

The method of test depends entirely upon the apparatus available. If an audio-frequency oscillator and an oscilloscope can be used, then much of the testing of straightforward in character. If such apparatus is not accessible, then it is necessary to judge the results by ear and either use the radio signal or adopt some source of artificial signal such as a gramophone pick-up.

In view of these numerous possibilities it is proposed here to consider the operation of a simple amplifier and to show how its reproduction can be checked with the aid of an oscillator and an oscilloscope. We can then pass to the consideration of various factors which will prevent correct reproduction from being obtained, and indicate how suitable remedies may be found. It is felt that from this discussion the reader will obtain a satisfactory grasp of the fundamentals involved and will then be able to devise tests for himself to overcome any shortcomings in the way of apparatus.

Amplitude Distortion. It has already been mentioned that in testing amplifiers it is desirable to start with a small signal to minimise the possibility of valve overloading. A certain signal is applied to the grid of the valve in question and the valve should be operating under conditions which permit the anode voltage to change in an exactly similar manner. The development of a dynamic characteristic from the ordinary static characteristics has been discussed, and in the example chosen it was shown that with a symmetrical input voltage the anode swing was also symmetrical. An examination of the characteristics will show whether this condition of affairs is likely to exist, and the matter may be put to the test by examining the waveform with an oscilloscope. Most oscilloscopes contain an isolating condenser in the input to the circuit, so that the input leads to the oscilloscope may be connected indiscriminately to grid or anode circuits or any part thereof without encountering difficulties due to the fact that the anode circuits are at a steady positive potential. Moreover, as explained in the discussion of oscilloscopes, it is customary to incorporate a deflection amplifier in the instrument itself, and this amplifier should be such that provided the deflection on the tube does not exceed the full tube scan no appreciable distortion results.

With such an instrument, therefore, it is possible to examine the waveform at successive points in the circuit, usually starting with the input (when the full gain of the deflection amplifier will be required) and then at successively later points in the circuit, reducing the amplifier gain and perhaps dispensing with it altogether when examining the output stage.

After a short experience it is possible to determine the presence of distortion quite simply. One of the commonest forms of distortion is that due to overloading of the valve when the grid swing runs beyond the point at which the valve ceases to operate in linear fashion due to anode current cut off or due to running into grid current. As explained in the chapter on oscilloscopes, the tube will not, of itself, discriminate between these two because the way in which the voltage appears on the screen is entirely dependent upon the connections to the tube, but if it is found that there is a flattening of one side of the wave, it is not difficult to decide at which end of the swing the overloading is occurring. From a knowledge of the input voltage and the grid bias on the valve any incorrect operating conditions can be located.

Milliammeter Tests. It may be noted that the anode current will usually give an immediate indication of overloading of this type. The valve should operate under conditions where the increases and decreases of anode current about the mean value are both equal so that the mean anode current of the valve remains unchanged when a signal is applied. If the valve is over-biased so that during some part of the negative swing the anode current is reduced to zero, the increase in anode current will be more than the decrease, so that the mean anode current will rise.

Conversely, if the valve is running into grid current there may be a tendency for the anode current to fall, though this does not necessarily follow. If the preceding stage is capable of driving the valve into the region where grid current flows, then the anode current swings will still remain symmetrical. If the preceding stage will not drive the valve—i.e. if the presence of grid current causes the input signal to be limited, then the waveform will become flat-topped on the positive peaks and thus unsymmetrical, causing a change in the anode current.

When dealing with output stages distortion may be found to arise from an incorrect anode load. With an amplifier the anode load is usually several times as high as the valve internal resistance in the case of a triode (though in the case of a pentode it will be considerably less). In either case its value is chosen to give the full signal required without overloading in the manner already explained.

In the case of an output stage, whether it be triode or pentode, there is an optimum load which will deliver the maximum undistorted power output, and in estimating this, and often for estimating the performance of amplifier valves, it is more convenient to use the anode current-anode voltage characteristics.

Load Lines. A set of these characteristics is plotted in Fig. 4.8. The operating point of the valve is determined by the actual anode voltage and the grid bias which in turn will determine the anode current. With a self-biased arrangement the last two factors are interdependent. Through this operating point we draw a line having a slope (inversely) proportional to the anode load. The simplest way of arriving at this load line is to choose two suitable values and draw a line through these and then draw a second line parallel to the first through the actual operating point. For example, a load of 8,000 ohms will permit 25 mA to flow with 200 volts. Therefore we can draw a line joining the 200 volt v_a point to the 25 mA i_a point. A load line parallel to this through the operating point will then be what we require. This has been done in Fig. 4.8, and it will be seen that the length of the line *PA* is approximately equal to the line *PB*. Actually, it is rarely found that these two are exactly equal, and experience shows that the distortion will not exceed about 5 per cent if $PA/PB = 11/9 = 1{\cdot}22$.

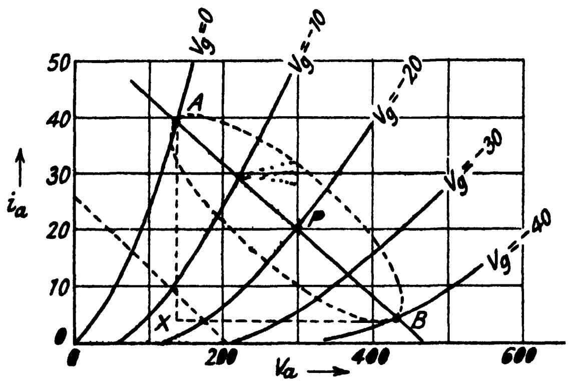

Fig. 4.8. Showing how a "Load Line" is plotted.

Too great attention should not be paid to this point because it is only part of the necessary considerations. Actually, the swings *PA* and *PB* are the peak swings, but it is necessary for distortionless operation that the excursion at any smaller values of the grid swing should be equally symmetrical. In Fig. 4.9 we have a case which often occurs with pentode or tetrode output stages where the peak swings are almost equal so that at first sight it would seem that practically distortion-free operation was being obtained.

Actually, however, it will be seen that the values of the excursion with half the grid swing are quite appreciably different, although with the full grid swing they are practically equal. Hence some distortion is present. Moreover, the form of the distortion will be such as to be symmetrical on each side of the waveform, and is therefore equivalent to the introduction of an odd harmonic, usually the third. This form of distortion is quite common with pentode or tetrode output stages, and it is found that the load which gives the least second harmonic usually introduces appreciable third harmonic. It is also usually possible to find a point at which the third harmonic is very nearly zero, but this usually occurs either at a point where the full output has not been developed or at a point where the even harmonics are appreciable. The choice of the best load with this class of valve, therefore, is a matter of compromise.

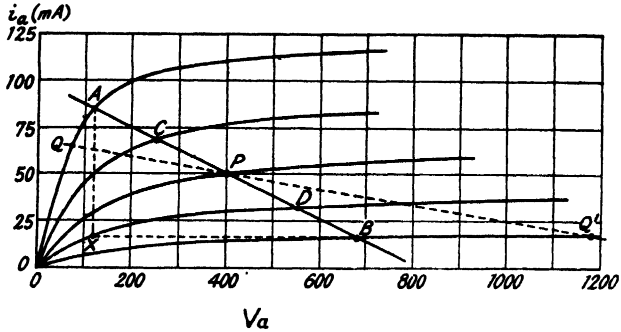

Fig. 4.9. With a Pentode the Voltage Swings become excessive if the load is too high.

Harmonics. The choice of the best load line is usually determined by the valve-makers and recommendations are suppled with the valve itself. For many purposes it is sufficient to make sure that the load is approximately correct because in fault-finding, at any rate, one is not concerned with small amounts of harmonic distortion and, provided the load line complies with the 11/9 rule already mentioned, the result will often be sufficiently satisfactory. This is the more so because the load line is only as shown when the load is a pure resistance. The presence of any reactive component such as inductance or capacitance introduces a phase difference so that the current and voltage do not go through the maximum and minimum at the same time. The effect of this is to cause the actual excursion of the operating point to follow an elliptical path, as indicated dotted in Fig. 4.8.

The calculation of the exact path is a matter of a little complexity, and it is not necessary for our present discussion to go into the matter more fully. The point is raised in support of the statement that for normal purposes an approximately correct operating condition is all that need be sought, because although the average loud speaker, by virtue of the fact that it is transforming the current it receives into mechanical energy, behaves very nearly as a pure resistance, there is some reactive component which invalidates any highly exact calculations.

It is of interest, however, to note why the asymmetry of the load lines just discussed is said to cause second or third harmonic distortion. In Fig. 4.10 we have represented the effect of adding to a pure sine wave a number of smaller components having frequencies of twice and three times the fundamental frequency. The exact shape of the resulting waveform depends upon the relative phase of the harmonic and the fundamental. For example, in Figs. 4.10 (*a*) and 4.10 (*b*) we have two waves containing exactly the same proportion of second harmonic distortion, but in one case the harmonic component is in phase, so that it goes through zero at the same time as the fundamental, whereas in the second instance it is not in phase.

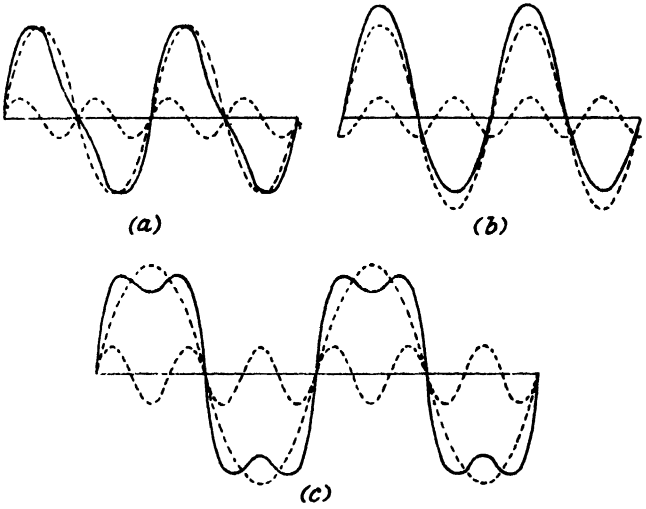

Fig. 4.10. Illustrating Distortion of Waveform by addition of Harmonics.

In practice it is distortion of the second type which is usually produced by a valve, for it will be seen that the effect is to flatten one half of the wave which is exactly what occurs if the anode swing is limited in one direction or the other, and this is the reason for the statement that any inequality of the two portions *PA* and *PB* of the load line will cause second harmonic distortion.

In the case of third harmonic distortion, it will be seen that this is such as to make the waves distorted but still symmetrical in character and, generally speaking, an odd harmonic produces waves in which the top and bottom halves are symmetrical, while with even harmonic distortion the top and bottom halves are dissimilar. It may also be noted in passing that experience indicates that the phase of the harmonic is not important. The effect on the ear appears to be just the same whatever the relative phase of harmonic to fundamental.

Optimum Output. The influence of the load on the power output can easily be seen from the characteristics. As the slope of the load line changes the power output will be found to change also. With a nearly horizontal load line we should obtain a large voltage swing, but very little change in anode current. This is the condition corresponding to a large anode load, and since the power is the product of the voltage and current, the actual power developed is small. As the anode load is reduced the voltage swing decreases, but the current swing increases, and the power rises until we pass through a point where we obtain maximum power output. Thereafter further reduction in the anode load causes the load line to become more and more vertical, which causes increased current swings and decreased voltage swings, and as the latter effect overcomes the former, the total power output falls off again.

The point at which maximum output is obtained is not the best operating point, because it will be found that there is considerable distortion here and the practical point is that at which the maximum power output is obtained without more than a certain pre-determined distortion. With a triode output stage this usually occurs at a load between two and three times the valve resistance. With a pentode valve a high anode load is undesirable because, as will be seen from Fig. 4.9, a nearly horizontal load line gives us a very large peak swing in one direction, which causes the anode voltage to rise to several thousand volts with consequent danger to the insulation, and often breakdown. On the other hand, with very small anode loads we obtain very little distortion, but at the same time little power output, because of the reduced voltage swing and the optimum load is again at some intermediate point where the load line is diagonal.

Since it is not convenient to make the loud speaker exactly matched to the valve in question—it being customary indeed to make the loud speaker impedance comparatively low because the speech coil usually consists of a small number of turns on heavy gauge wire—it is customary to incorporate a matching transformer. Any transformer with a load across its secondary behaves as if it were replaced by an equivalent load equal to n^2 times the secondary load where n is the transformer ratio. Knowing the actual impedance of the load, it is therefore a simple matter to determine the correct transformer ratio in order to give the required effective load.

When dealing with push-pull output stages the load line is determined in the same way, except that the operating point may be different. With a class A output stage there is no difference, but with a class B stage the operating point will be at some reduced value of anode current and correspondingly increased bias, because the valve only operates over that portion of the cycle which causes the anode current to increase (and the anode voltage to decrease). It is customary to neglect the remaining part of the cycle over which the anode current decreases, because this only contributes a small amount to the total power and the optimum load is determined by the application of the same principles as have already been discussed.

Each half of the output transformer must then be calculated in accordance with the principles just mentioned. Sometimes the output transformer is specified in terms of its effective anode to anode impedance, which will be found to be four times as great as that determined for each valve alone. This is confusing at first, but it arises from the square in the calculations. Thus, if we have a loud speaker with a load of 10 ohms and we find that the optimum load for one valve alone is 4,000 ohms, the transformer will have to have a ratio of $\sqrt{4{,}000/10}=20$.

The total transformer, therefore, will have twice this ratio and the apparent impedance between the outside terminals connected to the two anodes will therefore be $10\times 40^2=16{,}000$ ohms—four times as great as that for each half alone.

When dealing with an amplifier it is possible to determine comparatively easily what the actual anode load is. With a loud speaker this is not so easy. One can, of course, measure what the effective input impedance of the loud speaker is by applying a voltage across the terminals and noting the alternating current. The impedance is then given by dividing the voltage by the current. If this is not practicable an alternative method is to replace the loud speaker with a dummy load. If the same transformer is to be used the loud speaker speech coil should be disconnected and a load resistance connected in its place. The d.c. resistance of the speech coil can be measured with an ohmmeter and the effective impedance will usually be found to be of the order of twice this d.c. resistance. By adjusting this artificial load until the voltage developed in the anode circuit is the same as under actual operating conditions with the loud speaker in place, one is able to obtain an estimate of the effective loud speaker impedance.

Another method is to use an output meter, preferably of the type having a variable impedance or to use an independent output transformer and connect a suitable load across the secondary. Some method such as this must be adopted because the insertion of the resistance direct in the anode circuit invalidates the conditions owing to the heavy voltage drop produced by the passage of the steady anode current through the load. With a transformer the d.c. resistance is relatively small and only causes a drop of the order of 20 or 30 volts.

Cures for Overloading. So far we have only considered the question of distortion arising from overloading. If overloading of this sort is found it arises either from incorrect values of components or from the fact that the valve itself is either defective or is operating under incorrect conditions. The valve itself may be checked by the methods discussed in Chapter XI. A check on the mean or steady anode current will usually give an indication as to whether the valve is up to standard, because after prolonged use the anode current tends to decrease due to the deterioration of the valve, and if this is found to be so the valve should be suspected.

Incorrect component values must be located by the usual tests, having established the stage in the amplifier at which the overloading is taking place. A simple calculation, knowing the performance to be expected from the valve in question, will show whether the desired results are theoretically obtainable, and if it is then found that in practice they are not obtained it only requires the exercise of reasoning to determine whether the operating conditions are correct, and if not, what has transpired to make them wrong.

It must be remembered that overloading may be caused by defects in some stage other than that actually exhibiting the overloading. Thus, if there is some defect in the output stage causing reduced efficiency it will be necessary to apply an increased signal to the input. It is conceivable that the output stage could handle this, but that the preceding stage would not deliver the additional signal without overloading.

These forms of overloading, however, are by no means the only means of causes of distortion in amplifiers, and we must now consider other and more obscure forms of distortion.

Frequency Distortion. In any discussion on quality the question of frequency distortion must be considered. This term denotes the failure of the amplifier to amplify signals of differing frequency to the same extent. Usually it is found that over the middle frequencies the amplification is substantially uniform, but at very low and high frequencies the amplification falls off.

Prior to the cut off it is often found that the amplification is accentuated due to a resonance, while there are always possibilities of resonances in the networks causing certain frequencies to be accentuated or depressed.

The effects of inadequate frequency response are well known. The loss of the low notes causes the true bass tone to be missing, although the harmonics of the bass tone may lie within a portion of the frequency spectrum which the amplifier handles reasonably satisfactorily. If this is so, the ear, being very accommodating, will imagine the missing fundamentals to quite a creditable extent. The extent, therefore, to which real reproduction of the low frequencies below 100 cycles is necessary depends entirely on the excellence of the quality required

The upper frequencies are more troublesome because the higher overtones of musical instruments and the short transients and sibilant sounds (such as *t*, *p*, *s* and *th*) are very rich in high-order harmonics. Loss of the upper frequencies, therefore, produces a definite and easily noticeable change in the quality of music and causes articulation to be indistinct. If these upper frequencies are accentuated, however, as is often the case, the reproduction sounds shrill and harsh. If accentuation of the high notes is mixed with amplitude distortion, which in itself generates harmonics which ought not to be present, the results can be unpleasant in the extreme.

Response Curves. Checking frequency response is a simple matter. Arrangements are made to apply a constant input of varying frequency to the amplifier. A suitable valve or other voltmeter is then connected across the output stage, and the reading on this voltmeter is noted at the various frequencies. If the amplifier gives a uniform magnification over the whole frequency scale, the reading on this output meter will, of course, remain constant, but in practice it does not do so, there being variations at different parts of the frequency scale, which are shown by the variation in reading of the output meter.

The connection of the output meter depends upon the circumstances. If one is not interested in the effect of the loud speaker on the characteristics, as is very often the case, it is sufficient to connect the meter across the grid circuit of the output valve. The output valve itself should be left in circuit with a suitable resistance in the anode circuit in order to duplicate practical conditions.

If, on the other hand, one desires to include the magnification obtained from the output stage, then the voltmeter should be connected across the loud speaker or across a dummy load in the output stage designed to give the optimum result, according to which is preferable.

The meter, of course, must be of such a type as to cause as little interference as possible with the performance of the amplifier. A valve voltmeter is usually employed, but even so, care must be taken to avoid errors. Alternatively an output meter may be employed.

Where a large number of response curves is required it becomes worth while to devise some automatic recording device. For example, one may use a recording milliammeter instead of the customary meter in the valve voltmeter circuit across the output. Such an instrument is one which makes a mark on a piece of paper at a height corresponding to the actual current. The paper is then moved steadily past the pointer and in this way a continuous curve is traced. The movement of the paper must, of course, be linked up in some way with the low-frequency oscillator, so that the movement is proportional to the frequency at each point. A beat-frequency oscillator is practically essential for such a purpose, and with such an arrangement a mechanical link between the recording instrument and the frequency control on the oscillator is very easily arranged.

There are other ways of achieving the same result which need not be enumerated here. Mention, however, may be made of the cathode ray instrument which is discussed in Chapter XII. Here, the deflection on one pair of plates of the oscillograph is controlled by the frequency and that on the other pair, at right-angles, is controlled by the output. The spot on the cathode ray screen, therefore, traces out a response curve of the form required.

Distortion due to R.F. Currents. A form of distortion which is also liable to be present in the amplifiers of radio receivers arises from the presence of radio-frequency currents in the audio-frequency stages. When the signal has passed through the detector stage we no longer require the radio-frequency currents and provision is (or should be) made to by-pass these currents to earth, leaving only the modulation currents to be further amplified. If this by-passing is inadequate, or if by some other means r.f. currents are introduced into the audio-frequency stages, the valves will be called upon to handle grid swings in excess of what they are designed for. This gives rise to a curious form of amplitude distortion.

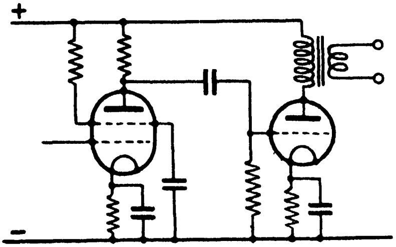

Fig. 4.11. R.C.-coupled Amplifier.

For example, in the circuit of Fig. 4.11 we have a resistance capacity arrangement which is normally so operated that the second valve never runs into grid current. If on top of the audio-frequency signal, however, we have superposed an appreciable amount of r.f. voltage the effective peak swing will be appreciably greater. This will cause the valve to run into grid current and the current so taken will charge the coupling condenser negatively, causing the effective grid bias on the valve to be decreased. In consequence the valve will behave as if it were over-biased and it will introduce serious amplitude distortion on the audio-frequency signal.

This is quite apart from any effect which the radio-frequency current itself might introduce because, although the r.f. cannot be heard as such, its presence is capable of setting up local oscillations or resonances which can further distort the quality. The general effect is to produce a cracked quality of reproduction.

In amplifiers having more than one a.f. stage it is quite possible for regeneration to occur at a radio (or supersonic) frequency, so that a high-frequency oscillation is generated in the amplifier itself, causing the effects mentioned above.

A good test for the presence of parasitic currents is to place one finger lightly on the grid terminal of the successive valves. The leak to earth so introduced will often check the oscillation and improve the quality. If a sharp plop or click is obtained when the finger makes contact it also indicates oscillation. With a normal set the presence of the finger will merely cut down the strength.

H.F. Chokes. Assuming that radio-frequency currents are found to be the cause of the distortion, we must then arrange to by-pass the energy from the low-frequency portion of the amplifier as effectively as possible. A good high-frequency choke in the anode circuit of the first valve is desirable. Too many of the chokes which are found in modern equipment are not of a sufficiently high standard to act as an effective barrier. An effective choke should have an inductance of at least 100,000 μH with self-capacitance of 3 or 4 μμF only. Coupled with the use of a high-frequency choke, the use of a by-pass condenser is a *sine qua non*. It is of no use whatever to endeavour to choke back radio-frequency (or any other form of) energy unless an alternative path is provided for the energy which is to be withheld. Therefore, on the live or high-frequency side of the choke one must connect a by-pass condenser, as shown in Fig. 4.12. The capacitance must not be too large or there is a danger of cutting off the top notes of the low-frequency reproduction, and, in general, a value of up to ·0002μF will be found to be sufficient.

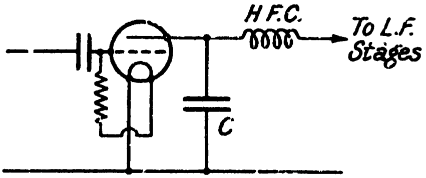

Fig. 4.12. The H.F. Choke must have a by-pass on the Live Side, as shown at C.

If the circuit is not provided with a by-pass condenser, therefore, the omission should be repaired. If a condenser is present, make sure that the choke is a good one before proceeding further.

Grid Stoppers. Further obstacles in the path of high-frequency currents may be placed by inserting stopper resistances in the grid leads. These resistances should have a value of the order of 100,000 to 250,000 ohms. They operate by reason of the capacitance between grid and filament of the valve, and the relative reactance of this capacitance at radio frequencies and low frequencies.

The equivalent circuit is shown in Fig. 4.13, from which it will be seen that we have virtually a resistance in series with a capacitance and it is the voltage across the capacitance which is actually applied to the valve. At low frequencies the capacitive reactance is very large and consequently the greater part of the voltage is developed across this capacitance. The resistance, therefore, has no effect in cutting down the signal strength. At high frequencies, on the other hand, the reactance of the capacitance is quite small compared with the resistance, and therefore most of the high-frequency energy is lost in the resistance; only a small portion thereof is actually applied to the valve.

The value should not exceed 250,000 ohms, or the upper audio frequencies will be affected. The design of stopper circuits is discussed in Appendix II.

A third method of by-passing the energy is to connect a small condenser across the secondary of the transformer or from the anode of the second valve to earth. These condensers must again be small in order to avoid by-passing the top notes in the reproduction, and generally speaking, methods such as this are not found necessary if the remedies already outlined have been put into practice. A practice which is often necessary in portable sets is the connection of a condenser of ·001μF to ·002μF across the loud speaker itself, or alternatively, across from the live side of the loud speaker to earth. This serves to by-pass such radio-frequency energy as does reach the loud speaker stage which, in a portable set, usually gets there by direct induction and not by passing right through the amplifier so that a heavy by-pass of this nature is necessary in order to minimise the defect. Needless to say, such a heavy by-pass as this has an adverse effect on the quality, but the results are more pleasant than the thin high-pitched tone which results when r.f. currents are present.

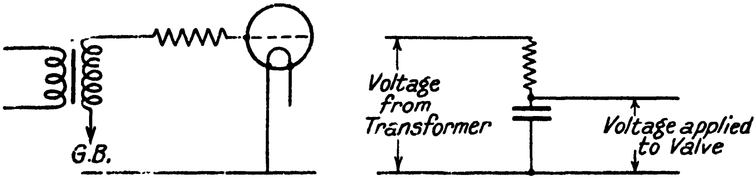

Fig. 4.13. Illustrating Action of Grid Stopper.

Saturation. Parallel Feed. If investigations prove, however, that distortion is not arising from the presence of radio-frequency currents, and if the quality is still bad on a weak signal, then one must look for some seriously incorrect values of the components. In a transformer-coupled amplifier, saturation of the iron circuit may be responsible for the trouble. The presence of the steady current in the anode circuit reduces the inductance of the primary winding of the transformer to a greater or less extent. If a transformer with an inadequate iron circuit is used after the valve which passes a fairly heavy anode current, then the inductance of the transformer primary may be reduced to a mere fraction of its normal value. The result of this will be that the reproduction of the transformer is quite inadequate for the circumstances and the quality will sound thin and reedy.

In order to verify whether this is happening, it is necessary either to replace the transformer with another transformer known to be of good quality and capable of standing up to the job, or to arrange a parallel feed to the transformer in question. This is done by feeding the high tension to the anode of the valve through a high inductance choke. The low-frequency currents are by-passed through a condenser on to the transformer as shown in Fig. 4.14. This may be hooked up quite external to the set, and if the quality improves then the transformer is not suitable for use directly in the anode circuit and must either be replaced or provided with some form of parallel feed.

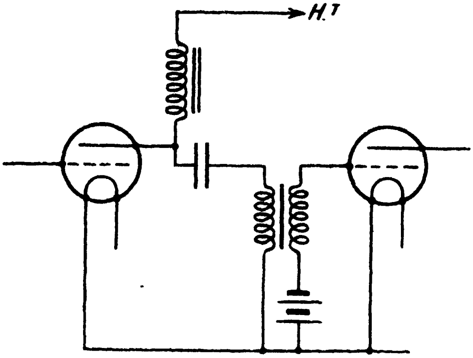

Fig. 4.14. Parallel Feed Circuit.

On the subject of parallel feed, it should be pointed out that the choke itself should have a high inductance of between 50 and 100 henries for preference. This is, of course, at the particular anode current which the choke is carrying.

Saturation may, of course, occur in an output transformer or choke with equally unpleasant results. The only remedy in this case is to replace the suspected component with one of proved performance.

Resistance Feed. Parallel feeding may be obtained by the use of a resistance instead of a choke, but this requires a certain amount of careful proportioning, for if the resistance is too high, the voltage drop is excessive and the voltage on the valve itself is reduced to too low a value. On the other hand, if the resistance is too low, it exercises a shunting effect across the primary of the transformer, and so defeats its own object, which is to maintain a high impedance in the anode circuit. Generally speaking, a resistance having a value equal to twice the valve resistance will be found satisfactory.

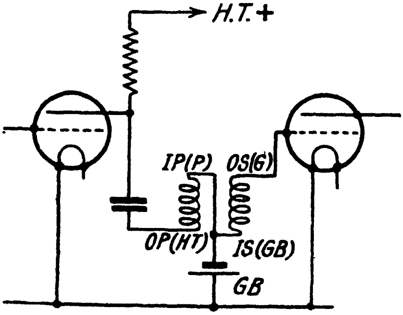

Fig. 4.15. Resistance Feed Circuit.

Resistance feed, however, requires to be used with caution as it is liable to introduce certain unsuspected troubles. This point is dealt with on page 91 in the discussion on decoupling circuits.

Fig. 4.15 shows a typical resistance-feed arrangement. Here the primary winding is so connected as to be in series with the secondary to give an auto-transformer action. This increases the step up by 1, so that if the turns ratio is 3 : 1 we obtain a step up of 4 : 1.

This arrangement is often adopted, but it will be observed that the leads to the primary are reversed in order to obtain the correct direction, and in some cases this makes a considerable difference to the characteristics. If noticeable lack of bass or treble is observed with an auto-coupled arrangement, therefore, this is one of the points to suspect.

Incorrect Values. Another form of distortion arises from incorrect values of grid leak in resistance-coupled amplifiers. If the grid leak is too high, the phenomenon known as "grid choking" results. Although normally no grid current flows, certain peak values result in excessive grid potentials, and a small amount of grid current is taken at the top of these peaks. The effect of this is to increase the grid bias momentarily, due to a building up of charge on the coupling condenser, as with a grid rectifier, and on a strong signal the grid bias may be increased by quite a considerable amount. If the grid leak is of too high a value, this charge cannot leak away fast enough, and the speech or music has a choked sound. On the other hand, if the grid leak is too small, then the bass reproduction suffers.

It is a good idea to check the values of the grid leaks and anode resistances of a resistance-coupled set. This may be done by the methods described in Chapter XI, and the values actually found may be compared with the rated values of the component and these in turn may be compared with what is theoretically sound practice.

The design of resistance-coupling circuits is discussed in the Appendix. As a general rule it may be said that for adequate bass reproduction the product of the coupling-condenser capacitance in μF and the leak resistance in megohms should be at least ·01.

The anode resistance should be two to three times that of the valve, and the grid leak should be approximately four times the anode resistance. This immediately determines the correct value of coupling condenser, and in a well-designed set this is the order of the values which will be encountered. If the values are different then suitable alterations should be made and the effect noted.

A trouble which must be suspected in this connection is that the coupling condenser has broken down. The method of testing for this has already been described, but a partial breakdown will result in the application of a small amount of positive bias to the succeeding valve, and this may distort the quality.

H.T. Line Coupling. A final possible source of bad quality is that due to feedback from the h.t. power supply. This is described more fully in the next section wherein it is pointed out that with even number of stages the h.t. line coupling is positive, whereas with an odd number of stages the coupling is negative. In this latter case, it has the effect of reducing the total amplification, although the maximum reduction under the worst possible conditions is only something like 20 per cent. The danger lies, however, in the fact that the reaction effect is different at differing frequencies, and this distorts the quality. With a battery, feedback may exist in a positive direction, but may be insufficient to cause actual oscillation, this depending upon the constants of the circuit. This type of distortion is even more unpleasant than the reverse feedback type, for it can be very violent in character, and may result in the accentuation of some frequencies and in the complete suppression of others.

Therefore, if all other ideas have proved unprofitable, battery-coupling should be suspected, and remedies should be put into operation as described in the final section of this chapter, dealing with self-oscillation in a.f. amplifiers.

Rattling. It is often suggested that the speaker itself is responsible for bad quality, but in the majority of instances this is not the case. Most modern loud speakers will handle far larger volume than they are called upon to deliver in ordinary practice, provided that the energy supplied to them is of satisfactory quality. This is not an invariable rule. Some loud speakers, for example, develop a rattle when the volume is increased, a fault that is particularly noticeable in some forms of moving-coil speaker where the diaphragm breaks up into resonances in the upper frequencies as soon as the volume is increased. As a general rule, however, one need not suspect the loud speaker, because this is only rarely found to be the cause of the trouble.

Detector Distortion. So much for the low-frequency amplifier itself. Distortion, however, can very easily arise as a result of the detector stage, and the trouble may be either an audio- or radio-frequency matter. We will consider the a.f. aspects here, the r.f. aspects being considered in Chapter VI.

There are three main types of detector, though the first is now mainly of academic interest. The three types are:

1. Anode-bend rectification.
2. Grid rectification.
3. Diode rectification.

Anode-Bend Detection. The simplest form of valve rectifier is that based on the curvature of the ordinary valve characteristic. If the valve is operated on the bottom bend of the characteristic, the application of a positive voltage will cause a relatively large change in the anode current, whereas further negative voltage will only cause a small alteration and the net result will be an increase in the effective current.

This type of rectifier is unsuitable for small signals, partly on account of its poor sensitivity and partly because it obeys a square law and hence introduces distortion. For larger applied voltages, however, a different condition of affairs obtains somewhat as illustrated in Fig. 4.16. Here the modulated portion of the signal operates over the straight-line part of the characteristic and the rectification is reasonably free from distortion. Also the slope of the characteristic is steep, giving good sensitivity.

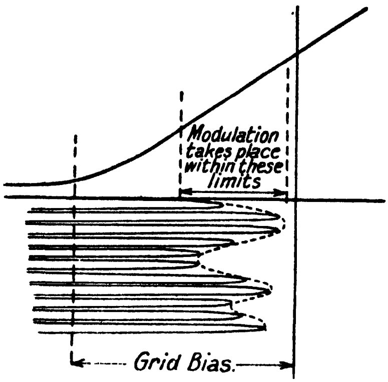

Fig. 4.16. Illustrating Linear Rectification with the Anode-Bend System.

It is obvious that to obtain satisfactory working under these conditions a high voltage must be placed on the anode of the valve (100 to 120 volts) and a large negative bias must be used. This bias should be about twice the normal bias for the valve used as an amplifier, with the given h.t. voltage. Secondly, the applied signal must be sufficiently large to sweep right past the curved portion at the base of the characteristic.

Grid Rectification. A form of rectifier which is in much more popular use is the grid rectifier, of which a skeleton circuit is shown in Fig. 4.17. A small blocking condenser is inserted in the grid lead of the rectifier with a leak from grid to filament or cathode.

On the arrival of a signal which makes the grid positive a small amount of grid current flows and charges up the condenser. The negative half-cycle has no effect. The successive positive cycles gradually charge the condenser up and thus automatically place a negative bias on the valve equal to the peak value of the applied signal. Thus the charge acquired is roughly proportional to the strength of the applied signal. This causes a variation in anode current, and provided the valve is working around a point where the characteristic is straight, the anode current variation is proportional to the modulation and distortionless rectification is obtained.

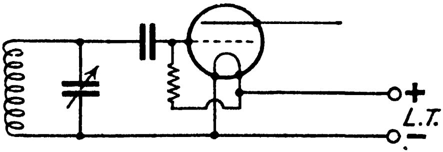

Fig. 4.17. Grid Rectification Circuit.

This form of rectifier is very sensitive to weak signals, but will only handle a limited input. Beyond this point the a.f. output not only ceases to be proportional to the input, but definitely falls off, as illustrated in Fig. 4.18. This shows how the audio-frequency output varies as the signal input is increased, the modulation depth being maintained constant.

The curves clearly show a fairly linear initial portion followed by a sharp limiting action beyond which the output falls off again. The curve marked H.F. is for a high impedance short grid-base triode, the "L.F." and "Power" curves being for valves having successively lower impedance and longer grid base.

Overloading is denoted by an accentuation of the sibilants and upper frequencies generally. It is often accompanied by a double hump in the tuning, the condenser tuning to the particular station at two distinct points comparatively close together.

The reason is that the signal strength at the actual resonant point is beyond the knee of the sensitivity curve (Fig. 4.18), so that the a.f. output is less than when the station is not quite in tune. This gives two peaks on either side and a depression at the actual tuning-point.

The remedy is to reduce the input or else to increase the anode voltage. The peak signal strength which a grid detector will handle is approximately equal to the grid bias which the valve requires when used as an amplifier under the particular high-tension conditions, and this is a useful rule to remember. Increasing the anode voltage increases the capabilities of the valve both as an amplifier and as a detector.

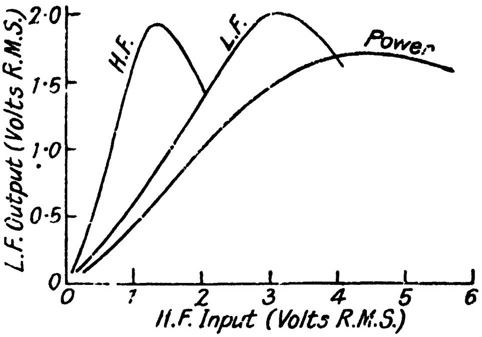

Fig. 4.18. Output from Representative Detectors (with 20 per cent Modulation).

Diode Detection. The overloading with a grid rectifier arises from the fact that the grid condenser charges negatively, thereby reducing the effective bias on the valve acting as an amplifier. For this reason, it is the practice in all modern receivers to separate the function of the detector and the amplifier.

A separate diode is used for the purpose, consisting merely of a cathode or filament surrounded by a small anode. It is connected in one or other of the ways shown in Fig. 4.19, both of which operate in the same way as the arrangement of Fig. 4.17. During the half cycle when the diode is conducting, the condenser *C* will be charged to the peak value of the applied voltage. During the next half cycle the charge will leak away through the resistance *R*, but since this is made of a high value the loss of charge is small. Hence the condenser will charge up negatively to an extent depending upon the strength of the signal and the voltage on the condenser, or, alternatively, across the resistance *R*, will vary from instant to instant in accordance with the modulation of the high-frequency signal. This low-frequency voltage can be transferred to an entirely separate amplifying valve, which can be adjusted to give the best amplifying conditions, and under these circumstances the output which can be handled is several times greater than with a grid detector.

The diode may be an entirely separate valve or it may be mounted on the same cathode or filament as the amplifying valve, but being of separate construction it is virtually a separate valve. Hence, we have such valves as the double-diode triode, comprising a simple a.f. triode with two diodes mounted on the same cathode. One diode is used for rectification and the other for automatic volume control as discussed in later chapters.

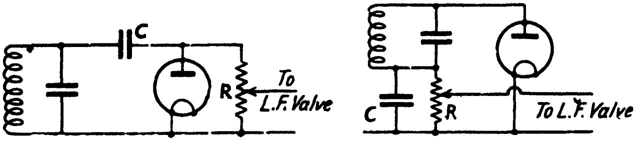

Fig. 4.19. Alternative Arrangements for Diode Detection.

In order to avoid transferring the steady potential developed by the diode circuit on to the a.f. amplifier, it is customary to use an isolating condenser and leak in the manner shown in Fig. 4.20. It is essential that the value of the grid leak in such a circuit shall be at least twice that of the diode resistance as otherwise distortion may be obtained on full modulation.

This is because, to a.c. voltage, the diode resistance and the grid leak are virtually in parallel so that the a.c. current is more than the d.c. current. This can obviously only be possible up to a certain depth of modulation.

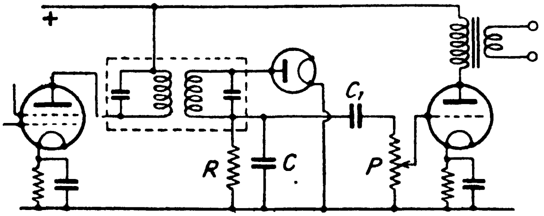

Fig. 4.20. Typical Arrangement of Diode Detector to Isolate the d.c. Voltage and to Provide a Volume Control.

If the mean condenser voltage is e, the peak modulation component will be me where m is the modulation depth. The peak modulation current will thus be me/Z, where Z is the impedance of the circuit to a.c. But this cannot exceed the d.c. current $=e/R$, so that the maximum depth of distortionless modulation is when $me/Z=e/R$, so that $m=Z/R$.

The impedance Z includes the stray capacitances in the circuit, but at medium frequencies we may neglect these, so that $Z=R$ and P in parallel $=RP/(R+P)$. The maximum modulation depth is thus $P/(R+P)$. If P is $4R$ we can modulate up to 80 per cent without distortion and the minimum value permissible for reasonable quality is $2R$, which allows 67 per cent modulation.

Diode Faults. Diode circuits show few faults in practice. They will handle much larger inputs than are normally required and give excellent quality except on very small signals. Should trouble occur, however, it indicates that:

(*a*) The diode is saturating, having lost its emission. This is easily checked, for a diode should give a current of 1 mA with a few volts positive on the anode. A saturating diode would give distortion on large inputs, but reasonably good quality on smaller signals.

(*b*) The diode may be biased incorrectly. Normally it should have no steady voltage on the anode, the positive anode voltage necessary to make the diode conduct being supplied by the signal itself. With a.v.c. circuits, however, as discussed in Chapter VII, negative voltages are applied to delay the action and if through a wrong connection or a fault such voltage is reaching the signal diode, distortion may easily result. This form of distortion would be more pronounced on weak signals.

To overcome the inherent distortion of a diode at small inputs the anode is sometimes given a small positive bias. This must not be confused with the negative bias just referred to.

(*c*) There may always be a fault in the associated circuits due to broken or incorrect resistors, defective condensers, etc. These must be checked by measurement. Voltage and current tests are not applicable since the diode has no h.t. supply and only takes a small fraction of a milliamp under working conditions. Hence definite measurement, or alternatively, replacement of suspected components is the only line of attack.

In particular, a broken or disconnected diode load will give bad quality. If the resistance R in Fig. 4.20 is broken, there is still an a.c. load in the diode circuit formed by C in parallel with C_1P. The circuit therefore will still work, but incorrectly, since there is no d.c. path for the diode current.

Time Constant. It will be clear that the condenser which is charged by the action of the carrier wave is steadily losing its charge through the diode resistance. Now this leakage must take place sufficiently rapidly to follow the highest fluctuations in modulation which may be impressed on the carrier. Then the effective voltage on the condenser is at all times strictly proportional to the strength of the carrier at that instant, which is what is required for faithful reproduction.

The time taken for a condenser to discharge is dependent on the value of both the capacitance and the resistance through which it discharges. The product of these two is called the *time constant* of the circuit, and, as explained on page 115 the value of CR (C being μF and R in megohms) should not exceed $\frac{1}{4}f$ where f is the highest modulation frequency to be handled.

Checking Detector Linearity. In the test laboratory it is often desired to check the linearity of the detector. A valve voltmeter is connected across a suitable portion of the detector circuit at which it will measure the low-frequency output. Care, of course, must be taken to ensure that all radio-frequency currents are adequately filtered out, either before they reach the impedance across which the audio-frequency is measured or, if this is not practicable, by including a high-frequency choke and small by-pass condenser across the valve voltmeter itself. Then by varying the input, the alterations in output can be noted.

There are two general effects to be examined. The first is the variation of low-frequency output with h.f. input with a constant modulation. This should be an absolute straight line. With triode or screen-grid detectors an overload point is usually experienced fairly early, giving a curve of the form shown in Fig. 4.18. Diode detectors usually do not overload until long after the output valve is fully loaded.

The second point requiring investigation is the variation of low-frequency output with a constant radio-frequency input but varying modulation. This again should be a straight line, and once more it is often found that there is a departure from the ideal. The test should be made at two inputs, one small and the other near the overload point, for it may be found that although a detector handles a strong signal with a weak modulation quite satisfactorily, it is no longer suitable for a high percentage of modulation.

All these measurements, of course, depend for their accuracy on a precise knowledge of the modulation so that the methods of adjustment and measurement of the modulation in the radio-frequency oscillator must be above reproach.

Overloading may be experienced not only in the detector, but in other portions of the low-frequency amplifier. It is, therefore, sometimes convenient to examine the amplifier in part or as a whole with a constant frequency, but varying amplitude on the input. Right up to the full output from the receiver there should be a straight-line relationship between output and input. If any part of the receiver is overloading the curve will turn over towards the top and begin to limit, and by suitable elimination of the various stages it is possible to decide just where the trouble is occurring.

Harmonic Analysis. There are numerous other forms of test which are outside the scope of this work, dealing as it does with comparatively straightforward methods. Reference, however, may be made to the analysis of the harmonics present in the output. We shall discuss briefly two cases, one concerned with the estimation of the total harmonic contents and the other with the individual analysis of the harmonics.

It may be emphasised at the outset that for such harmonic analysis, the input waveform must be particularly pure. Therefore, it is advisable to choose a frequency from the low-frequency oscillator at which the harmonic content is known to be fairly low, and to insert between the oscillator and the input to the amplifier a low pass filter of the type shown in Fig. 4.21. This filter can be adjusted to have a cut-off frequency at the frequency being used. It will then very rapidly attenuate any frequency above this, and quite a simple filter will serve to reduce the frequency of twice the fundamental by ten times. If the second harmonic content in the oscillator was originally 5 per cent it has now been reduced to 0.5 per cent which is negligible.

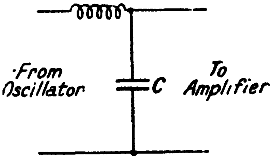

Fig. 4.21. Low Pass Filter for Eliminating Harmonics.

It is desirable that the filter impedance should be roughly correct. If R is the load into which the oscillator is intended to work and f is the cut-off frequency in c/s, then

$$L = R/\pi f \text{ and } C = 1/\pi f R$$

where L and C are the inductance and capacitance in henries and farads.

The output from the amplifier is then analysed under the appropriate (full load) operating conditions. One of the most convenient methods is a bridge circuit described by H. A. Thomas (*Journal I.E.E.*, June, 1932). A circuit of this is shown in Fig. 4.22. In series with the load in the output circuit of the receiver are two low resistances, R_1 and R_2. A two-way switch connects the analysing network across each in turn.

In position 1 the analysing network is a bridge comprising R_3, R_4, R_5 and the tuned circuit LC, which is all connected across R_1. If LC is tuned to the fundamental frequency and R_4 is suitably adjusted, the fundamental can be balanced out, and if the wave were pure the indicator across AB would give no reading. In practice it still reads, so that the residual indication is proportional to the harmonics.

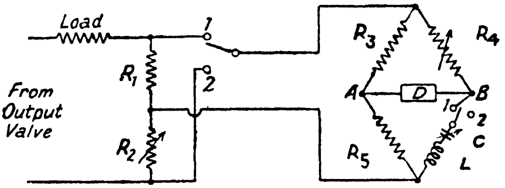

Fig. 4.22. Bridge Circuit for Measuring Harmonics.

The switch is now thrown to position 2, which places the indicator in series with a resistance network across R_2, and the indicator AB thus reads a value proportional to the full current comprising fundamental and harmonics. The arm LC is open so that no balancing out results. If R_2 is adjusted to give the same reading on the indicator as before it can be shown that the total harmonic content is simply R_2/R_1.

For proof of this method and more detailed particulars the reader is referred to the paper by Thomas already quoted. In practice the indicator across AB has to be fairly sensitive so that an amplifier is usually used.

Absorption Method. Another method, rather simpler, is to absorb the fundamental with a bridge network, as shown in Fig. 4.23. The network shown is equivalent to a normal bridge circuit but has the advantage that one side of both input and output are common and may be earthed.

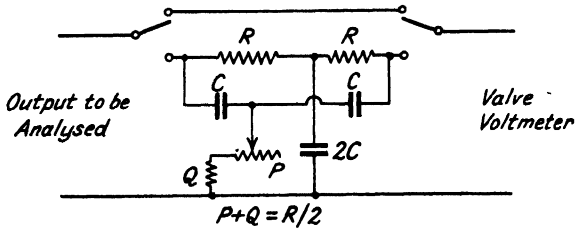

Fig. 4.23. Circuit for Absorbing the Fundamental.

The network absorbs very sharply at a frequency $f=1/2\pi CR$. The centre limb is made variable over a small range and serves to counteract small discrepancies in the rest of the network, the values of which need therefore only be accurate to about 5 per cent.

By varying the value of P, and also varying the input frequency very slightly until a minimum reading is obtained on the valve voltmeter, the fundamental may be practically eliminated. The voltage left is the total harmonic (plus hum) content. By noting the reading with the filter out of circuit, a simple calculation gives the total percentage of unwanted signal—a mixture of harmonic plus hum (if the amplifier is mains driven), plus noise.

Resonance Method. For a complete analysis of the individual harmonics the circuit of Fig. 4.24 may be used. In series with the normal output load for the receiver is a small resistance across which is tapped the tuned circuit. The voltage across the coil is measured with a valve voltmeter and by adjusting the circuit to resonate first with the fundamental and then with the successive harmonics, the proportion of each may be determined with considerable accuracy.

It is easy to show that the voltage across the coil is simply $IR_1L\omega/R$ when the circuit is tuned, R_1 being the small resistance in series with the load and R the total resistance of the circuit R_1LC.

Obviously, if R is constant the voltage developed across the coil is proportional to the harmonic voltage multiplied by the order of the harmonic. In other words, with the second harmonic since the harmonic frequency is twice the fundamental frequency, the relative voltage will be twice as great and the actual harmonic content is obtained by dividing the voltage obtained by two. This is very convenient because the harmonics become smaller as the order of the harmonic increases, so that the automatic multiplication of the voltage renders them more easy to check. For example, if the voltage across the coil at fundamental frequency is 87 and that across the coil when it is tuned to the fifth harmonic is 7, then the percentage of the fifth harmonic is $(7/5)/87 = 1{\cdot}38$.

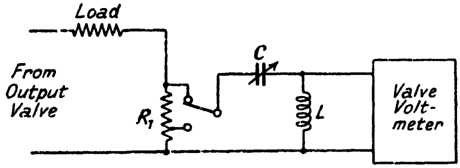

Fig. 4.24. Resonance Method of Harmonic Analysis.

Two points should be noted with this method. Firstly, the voltage at the fundamental frequency will be usually at least ten times as great as that developed by any of the harmonics, which means that either the voltmeter must have a suitable range switch or, more conveniently, the resistance R_1 across which the tuned circuit is tapped may be reduced to one-tenth of it's normal value for the fundamental measurement only.

The second point is that the resistance of the coil is not constant with frequency, but increases somewhat rapidly. It is desirable, therefore, to measure this resistance at various audio frequencies and plot a curve showing the variation with frequency. This may be done by applying a known voltage across the coil tuned with a condenser and inserting a milliammeter in series. As the condenser is tuned to the frequency under consideration the current will, of course, rise in the usual manner to a maximum. At this maximum the current is equal to the applied voltage divided by the effective resistance of the circuit, and if this measurement is made for a number of audio frequencies it is easy to arrive at the effective resistance.

The result of this increased resistance is that the voltage developed by the various harmonics is not as great as it should be. Therefore, the voltage obtained at any harmonic position should be multiplied by R'/R where R' is the resistance of the circuit at that particular frequency and R is the resistance at the fundamental frequency.

The total harmonic content is obtained by taking the vector sum of all the individual harmonics. That is, if H_2, H_3, H_4 are the harmonic contents of the second, third, fourth, etc., harmonics the total harmonic content is:

$$H = \sqrt{H_2{}^2 + H_3{}^2 + H_4{}^2 + \ldots}$$

Oscillation in A.F. Amplifiers. We now come to the last form of trouble in amplifiers, namely continuous oscillation. This may be of various types, the oscillation ranging from a high-pitched whistle to a very low frequency "popping" often referred to as "motor-boating," owing to the similarity of the noise of the exhaust of a motor-boat engine.

Oscillation may arise due to actual coupling between the various components. Low-frequency components, as a rule, are mounted on iron cores, and therefore the fields are confined. Nevertheless, it is possible with a circuit which is operating really efficiently, for stray fields to leak back from the end of the amplifier to the beginning and set up a continuous oscillation or a tendency thereto. The difficulty is largely overcome by shrouding the components in iron cases or by earthing the iron cores so that inter-action is only experienced in a very limited number of cases where the components have to be crowded together in a very confined space.

A more likely form of trouble is that arising from coupling between the output and input leads. Quite a small coupling may suffice to set up a continuous oscillation, particularly with a powerful amplifier, or one which already has a tendency towards instability from some other cause. For example, a set with two a.f. stages operating on a run-down battery will be in an unstable condition. If the loud speaker leads are brought near the detector, or even if the speaker is placed close to the set, whistling will very often occur.

However well designed an amplifier may be, coupling between output and input will introduce a reaction effect which will either cause instability or introduce damping and cause the system to operate with reduced efficiency. Portable receivers are very prone to trouble of this nature.

Common Impedance Coupling. By far the most common trouble in audio-frequency amplifiers is due to common impedance coupling. The circuit shown in Fig. 4.25 illustrates a two-valve amplifier, and it will be seen that the signal currents in the anode circuit of V_2 return to earth via the h.t. supply, which may be a battery or a mains unit. But this h.t. supply is not of negligible impedance. It will have some impedance, of a character depending on its type, which is represented in Fig. 4.25 by Z.

The signal-frequency currents flowing through this impedance develop a signal voltage across it. It will be seen, however, that this impedance is also included in the anode circuit of V_1, so that the signal voltage is introduced into the anode circuit of this (and any other) preceding stage.

This feedback voltage will thus be added to the legitimate signal voltage already existing at that point. It is unlikely to be directly in phase or anti-phase with the existing voltage, but it will usually have a substantial component either in phase with or opposition to the normal signal. If it is in opposition, the overall amplification of the circuit is reduced, while if they assist, the amplification is increased. The effect is cumulative, for increased amplification means more voltage applied to the last valve, more current through the common impedance, and consequently more feedback, and in quite a large number of cases the feedback is sufficiently great to cause a continuous oscillation.

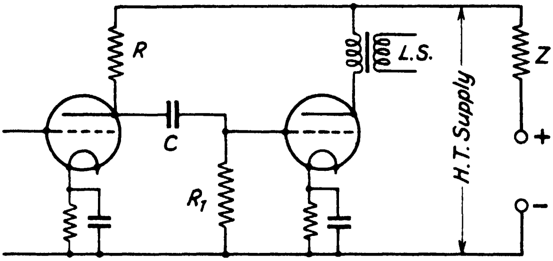

Fig. 4.25.
Illustrating feedback due to common impedance in h.t. line.

The frequency of this oscillation depends upon the character of the common impedance. If it is a high-tension battery, the oscillation is usually in the form of a high-pitched whistle. In the case of a mains unit, which contains inductance and capacitance in its smoothing circuit, the oscillation is usually of a much lower pitch and has a frequency of 3 or 4 per second only, whence the term "motor-boating" is derived.

It can be shown mathematically that with an even number of valves, the feedback is in a positive direction, tending to produce self-oscillation, whereas with an odd number of valves, the feedback is negative. Positive feedback may still occur, however, between two adjacent valves.

The maximum decrease is limited to something like 20 per cent, but it is nevertheless sufficient to produce a noticeable loss of efficiency, as explained on page 78, while a further trouble is that the feedback varies with the frequency and, therefore, introduces distortion. The methods of combating the trouble are the same whether the feedback is positive or negative, and are thus applicable to all forms of circuit.

De-Coupling Circuits. The method in general use is to provide filter circuits whereby the low-frequency currents do not pass through the battery or mains unit as the case may be. Such a method is shown in Fig. 4.26, where the filtering is applied to the first valve.

A 50,000 ohm resistance is connected in series with the h.t. supply, and the junction point between this resistance and the normal circuit is by-passed to earth through a large condenser of 2μF. The low-frequency currents, having passed through the primary of the transformer, prefer to go through the 2μF condenser to earth since this only has a reactance at 25 cycles of 3,200 ohms, which is much smaller than the 50,000-ohm resistance. The voltage applied across the whole circuit must, of course, be sufficiently high to allow for the voltage drop in the 50,000-ohm resistance. Otherwise there will not be adequate voltage on the anode itself.

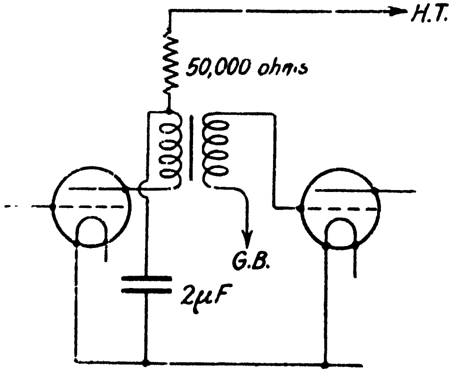

Fig. 4.26. De-Coupling Circuit.

It is, of course, possible to use other values of de-coupling resistance than 50,000 ohms and care must be taken that the very act of de-coupling does not introduce distortion by reducing the effective anode voltage too much. In general, the de-coupling resistance should be kept to the lowest value which is effective in curing the trouble unless the h.t. voltage can be increased as required to make adequate compensation.

In general, the product of the de-coupling resistance R (in ohms) and the by-pass capacitance C (in μF) should be about 80,000 for a single stage. If two successive stages are de-coupled the product RC should be about 200,000 for the first stage and 50,000 to 80,000 for the second stage. An a.f. choke is sometimes used instead of a resistance for de-coupling but this is not satisfactory in mains sets where the frequency of the oscillation is so low that, to be effective, the choke would require an inductance approaching 1,000 henries.

It may perhaps be remarked in passing that distortion produced by battery coupling is not likely to be indicated by a milliammeter, whereas distortion due to overloading is indicated at once by the lack of steadiness in the anode current.

De-Coupling and Resistance Feed. It is often thought that a parallel feed system is inherently de-coupled. This is not so with resistance feed. Consider the circuit of Fig. 4.27 (*a*). The l.f. current in the anode circuit has a choice of two paths, one through the resistance *R* and the other through the condenser *C* and the primary of the transformer *L*. A little calculation shows that the latter path has several times the impedance of the resistance at the middle audio frequencies, so that the current is actually shunted through the supply circuit instead of being diverted from it.

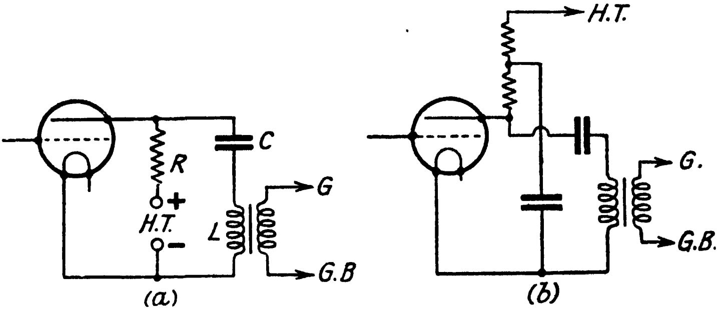

Fig. 4.27. Resistance Feed does not De-couple a Circuit and Additional Precautions may be Required as Shown.

Hence it is still necessary to de-couple the circuit if line coupling is likely to occur. If there is adequate voltage available this may be done with a resistance-capacitance filter as shown in Fig. 4.27 (*b*).

R.F. Feedback. Line coupling is not only troublesome in low-frequency stages, but also in high-frequency circuits, and the methods of de-coupling in r.f. circuits are dealt with in Chapter V. It is relevant to remark, however, that if the same supply is used for both high-frequency and low-frequency stages, as is nearly always the case, high-frequency voltages set up by the r.f. currents flowing through the battery are introduced into the low-frequency stages and this is another means by which r.f. currents can be introduced into an a.f. amplifier. The only method of keeping them out is to treat them at the r.f. portion by de-coupling the r.f. stages, and in order to ensure that no trouble is being experienced in this direction, it is desirable to disconnect the r.f. stages or render them inoperative by taking out the r.f. valves when checking over the amplifier in order that one shall not obtain conflicting effects, tending to mask the real source of difficulty.

A.V.C. Oscillation. In a set employing automatic volume control an oscillation similar to motor-boating may arise due to r.f. instability. The voltage produced at the detector by the oscillation, however, runs back the gain of the r.f. stages and checks the oscillation, which then builds up afresh, so that the set is continually falling in and out of oscillation at a very low frequency, depending on the time constant of the a.v.c. circuit.

At first this may be mistaken for a true "motor-boat," but if the disconnection of the r.f. stages cures the trouble it is clear that the fault lies prior to the detector. It must be located and cured by the methods laid down in Chapter V.

CHAPTER V

TUNING TESTS

WHEN we come to deal with the tuning circuits of a receiver we encounter entirely different conditions. The tuned circuits consist of an inductance with a capacitance either in series or, more usually, in parallel. The values are so chosen as to tune to the frequency of the incoming radio signal and either the inductance or the capacitance (usually the latter) is made variable to permit the tuning point to be varied over a range of frequency.

The types of fault encountered are threefold.

(1) Circuit fails to tune.
(2) Circuit tunes to an incorrect frequency or over an incorrect or insufficient range of frequencies.
(3) Circuit accepts frequencies other than the true wanted frequency.

Effect of Test Circuit. We shall consider these possibilities shortly. Before doing so, however, it is desirable to call attention to a point of paramount importance, namely, the effect on the circuit of the apparatus used during the test. It is an axiom in all testing that any apparatus used for the injection of a test signal or for the examination of the effects produced shall not appreciably influence the behaviour of the circuit in question.

Reference has already been made to this matter in the discussions on audio-frequency testing. The influence of the current taken by the voltmeter when making voltage tests is a typical example while there are numerous more subtle effects to be guarded against. At radio frequencies these other effects become of major importance.

Let us consider, for example, the simple circuit of Fig. 5.1. This is a simple battery detector circuit. Voltage is picked up on the aerial and the currents which flow are passed through a coupling coil, inducing voltages in the main circuit, L_1C_1. The current which flows is limited by the impedance of the circuit, which we make a minimum by "tuning" the condenser C_1 so that its reactance is equal (and opposite) to the reactance of the coil L_1. When this happens the current is only limited by the *effective* resistance of the coil and this current flowing through the coil develops a voltage several times greater than the original voltage induced from the aerial coil.[1]

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[1] If e is the induced voltage the current is $e/\sqrt{R^2+X^2}$, where R is the resistance and X is the reactance$=L\omega - \frac{1}{C\omega}$. L and C are the inductance and capacitance and $\omega = 2\pi \times$frequency. When $L\omega$ is made$=1/C\omega$, $X=O$ and the current is simply e/R.

The voltage across the coil is $iL\omega = e\frac{L\omega}{R}$. The "magnification" of the circuit is thus $L\omega/R$. The symbol Q is often used for this and clearly the better the circuit the higher the value of Q.

Now we can inadvertently make the performance of the circuit considerably poorer than it should be. If we connect across the circuit any detecting device of low resistance we shall introduce losses which will increase the effective resistance of the circuit and so reduce the voltage developed by the coil. The detecting device will in any case have some self capacitance so that the first effect will be to mistune the circuit and this must be corrected by a retune of the condenser C_1.

The tuning capacitance is then made up partly of C_1 and partly of the detecting device and if C_1 is small the detecting device may constitute a considerable proportion of the total, in which case any losses which it contains (apart from its input resistance as measured by d.c. methods) will have a marked effect.

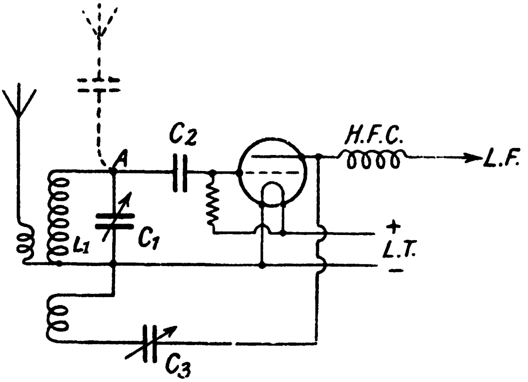

Fig. 5.1. Simple Detector Circuit.

Equivalent Resistance. An input resistance which could safely be neglected at audio frequencies may be serious at r.f. A tuned circuit may be considered to be equivalent, at resonance, to a resistance L/CR, where L and C are the inductance and capacitance and R is the effective r.f. resistance.[1] With quite a normal circuit this may be of the order of 250,000 ohms. If the detecting device has a similar resistance the effective resistance of the tuned circuit will be halved and the voltage developed halved in consequence.

Many forms of modern circuit have much higher "dynamic" resistances than this so that a parallel resistance as high as a megohm may seriously degrade the performance.

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[1] The current we are concerned with here is the circulating current. When we wish to consider the effect of a resistance across the circuit it is more convenient to regard the circuit from outside, as it were. From such a viewpoint the condenser and inductance are in parallel, and a current flowing in one direction in the coil at any instant will clearly be flowing in the opposite direction in the condenser. The two will in actuality nearly cancel each other out so that the circuit looks like a very high resistance, the value of which can be shown to be L/CR. This is called the dynamic resistance.

Effect on Tuning. The alteration of tune due to the additional capacitance of the detecting device is not the only such possibility. We may be able to use the existing valve as a detector. In the simplest tests we should do so, noting the a.f. voltage developed by some suitable method. But if we find the circuit fails to function a convenient test is to remove the aerial from the aerial coil and connect it to the top of the circuit. To do this directly would introduce the whole of the aerial capacitance across the circuit which would immediately alter its tune considerably—possibly so much that no reduction of the capacitance C_1 would enable the tune to be restored.

The effect can be minimised by connecting the aerial through a small series capacitance which would probably permit the circuit to be tuned satisfactorily, but even so it must be remembered that the aerial is not by any means a "good" condenser but has considerable losses so that the efficiency will be reduced. For all that, if this re-arrangement now permits the circuit to function, we have localised the defect to the aerial coupling coil which may be examined accordingly.

Actually the use of a coupled aerial is adopted by designers to minimise the effect of the aerial. Even with a coupling coil some part of the aerial loss is transferred to the tuned circuit but it is possible to design the number of turns and their location to give the best compromise for the particular requirements.

Another pitfall is to be found if we decide not to rely upon voltages collected by the aerial but to use a signal generator or test oscillator instead. Such an instrument would have a low output resistance of the order of 10 or 20 ohms and if this is connected across the aerial coil direct it would act as a short circuit. This would not only seriously reduce the performance of the circuit but would reduce the effective inductance by a large amount so that the tuning would be completely upset.

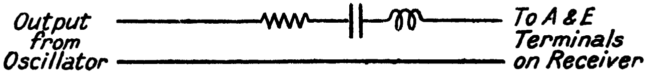

Fig. 5.2. Dummy Aerial for use in Set Testing.

To avoid this the test signal should be introduced through a "dummy aerial," which is a circuit having equivalent characteristics to a typical aerial. Such a circuit is shown in Fig. 5.2, though for many tests the use of a simple condenser of ·0002 μF capacitance is sufficient, the effect of the inductance and resistance being small.

Test on Simple Detector. Bearing these factors in mind let us consider some possible faults on the circuit of Fig. 5.1. Let us suppose that even when the tests just described have been made no reception is obtained. Either the tuning circuit itself is at fault, or the connections to the detector valve are incorrect. Check the grid condenser, and make sure that this shows an open circuit, indicating that the condenser is not short-circuited. This does not, of course, show whether the condenser itself is sound, for a complete break inside the condenser would give the same indication with this form of test as a proper condenser. In order to ensure that the condenser is really satisfactory, an additional condenser of say ·0001 μF capacitance should be connected across the grid blocking condenser, that is to say, in parallel with the condenser C2 in the figure. If the original condenser has broken down, this condenser will take its place and rectification will be produced.

Assuming the grid condenser to be in order, however, attention should be turned to the tuning coil. Test the continuity of the coil with an ohmmeter. If the coil is broken, then the damage must be found and repaired.

Next, see that the coil is correctly connected to the tuning condenser and check the insulation of the condenser by seeing that it registers an open circuit on the ohmmeter. For this purpose, of course, the coil must be temporarily disconnected, as this, being normally across the condenser, will cause a short circuit indication to be obtained unless it is removed.

If the condenser does not show an open circuit when tested in this manner, then the plates are touching somewhere or some other short circuit exists across the condenser, and this should be located and removed. Many modern condensers are provided with small trimmers across them. If a short circuit is found but is not apparent, look to the trimmers, as these are a fruitful source of trouble.

It may be mentioned here that the condenser spindle has been known to slip, so that rotation of the dial is possible without moving the plates round. Such a fault is particularly troublesome with totally screened condensers, as one can spend some time without suspecting such a simple defect.

If this does not clear the fault, start removing unnecessary portions. Connect the aerial to the top of L_1 as described and disconnect the aerial coil. It may have a short circuit across it.

The same applies to the reaction coil and in fact any subsidiary circuits should be removed as completely as possible. Ultimately signals will be obtained. The removed portions may then be reinserted one at a time until the defect is located.

As always, *only make one change at a time.* Otherwise the real cause of the trouble may be masked.

When all these points have been looked to, the circuit should tune in approximately the correct position (allowing for any alteration which may have been made to the circuit). If there is any discrepancy the circuit should be examined further as discussed under the heading of Incorrect Tuning.

Checking Reaction. Although reaction is little used, it is profitable to discuss the subject briefly. If, in the circuit shown, the reaction were not operating, the coil should be tested for continuity, and also for direction if it is visible. If it is not visible, then the only test which can be made is to reverse the leads to the coil and see if any better results are obtained. Where the coil is visible, however, it is always possible to check it by the following simple rule. The winding on the grid and anode coils should be continuous in direction. For example, if one starts at the grid point of the circuit and the winding goes clockwise to the filament, then it should continue to go clockwise from the filament (or h.t. +) to the anode. If the winding goes clockwise as far as the filament, and then the reaction coil traced from the filament (or h.t.) end to the anode end, goes in the opposite direction, the winding is in the wrong direction to produce oscillation.

If the coil is correctly connected and is continuous and still produces no reaction, the circuit is broken at some point. If the reaction effect tends to increase signals, but is weak, the value of C_3 should be increased slightly.

Too much increase is not desirable and if the circuit still behaves badly the h.f. choke should be suspected as it may be assumed that the r.f. currents are being allowed to pass too readily through some channel other than the reaction circuit. This matter is discussed further in Chapter VI.

Aerial Circuit. Having verified that the tuning circuit is correct, it remains to see that the aerial coil is right. Remove the aerial from its present position and connect this to its proper terminal, removing the ·0001 μF condenser. Results should now be satisfactory, but if they are not, then test the aerial coupling coil for continuity. It must be remembered, of course, that with a coupled aerial circuit, the results are usually distinctly weaker than with the aerial coupled straight on to the grid end of the coil through a ·0001 μF condenser. It is possible with a coupled aerial winding to get much the same strength as with a ·0001 μF condenser, but it is more usual to arrange matters to give rather less strength than this in the interests of selectivity. Therefore, a certain drop in signal strength may be anticipated, but if the drop is serious, the aerial coupling is insufficient, or, possibly, too great since too many turns give the same effect.

This question of the tune of the aerial itself is an important one and may be discussed further with advantage. As already explained, it is customary to connect the aerial to the first tuning circuit either by means of a tap on the coil or through a small coupling winding. The choice of the correct coupling is important.

If the coupling is too small the signal strength is weak. If it is too large the signal strength begins to fall off again and the selectivity of the circuit becomes bad. There is a definite optimum coupling, but this varies for each aerial, and it is necessary to adopt a compromise which will suit the majority of aerials.

It may be that the particular aerial in use is long or of a high capacitance, in which case the tuning will be flat. The inclusion of a ·0003 μF condenser in the aerial lead will often help matters.

Further trouble arises in dual range coils. One aerial winding is sometimes used for both wave-bands, but practical experience has shown that this is unsatisfactory, for if the coupling is right for the long waves it is much too tight for the 200–600 metre band and it is better to use a separate tapping or coupling winding on each wave-band, or a tap through a condenser on to the short-wave section to obtain an equivalent effect.

Another difficulty which is often experienced is a break-through of powerful local short-wave stations at the bottom end of the long-wave scale. This is due to the aerial coupling winding and the aerial capacitance tuning to some point in the medium-wave range. It may sometimes be overcome by connecting a small condenser across aerial and earth.

These last-mentioned troubles, however, are matters of design rather than fault-finding, and cannot be considered fully in the present work. In any case, most modern receivers include at least one short-wave range, with entirely separate coils for each range.

The change-over or short-circuiting switches used in multi-range coils are liable to give trouble, due to what is known as a high-frequency contact resistance. When tested with an ohmmeter or similar method the contact appears good, but in reality the small high-frequency voltages are unable to overcome the resistance between the contact points or springs. This resistance is due to a slight film over the metal, which can only be removed by cleaning the faces. A solution of carbon tetrachloride sprayed on to the switch contacts is excellent for this purpose.

Incorrect Tuning. It may be found that the circuit does not tune correctly. This will be due to incorrect values of the components or to the presence of some spurious effect. For example, it may be that, due to a wrong connection, a faulty switch or similar cause, the aerial coupling coil has become connected to the wrong end of the tuning coil. If this is connected to the grid end. then it is clear that the aerial capacitance has been connected across the whole coil, as in Fig. 5.3, and as has already been pointed out, this completely spoils the tuning properties.

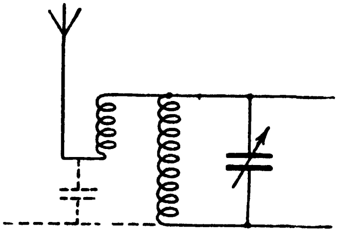

Fig. 5.3. If the Aerial Coil is Connected to the Wrong End of the Secondary Coil the Tuning will be Upset.

Another source of trouble is short-circuited turns. If due to careless winding or damage in handling two or more turns come into contact, the inductance of the coil will be decreased, and the capacitance required to tune to a given wave-length will be high and the output reduced because of the losses introduced by the short circuit.

Such a fault is difficult to locate simply, except by this very fact of incorrect tuning. The subject is dealt with in Chapter XI.

Absorption Effects. A defective switch may also introduce trouble due to failure to perform some operation on another circuit from the one under consideration. For instance, modern receivers usually provide a number of ranges each with separate coils. One of these coils may tune with its own stray capacitance to a frequency within the tuning range of some other coil. To avoid this the coils not in use are often short-circuited. If the switch is defective this short circuit may be ineffective, resulting in a more or less sharply defined band of frequency (on one of the adjacent coils) over which reception is very poor.

In superhet oscillators the absorption may be heavy enough to stop the oscillation so that no signals at all are receivable. Absorption effects usually emanate from a coil which covers a wave-band higher (in wave-length) than the one in which the defect is noted.

Band-Pass Tuners. These remarks do not exhaust the possibilities of tuning faults. The great majority of such faults, however, occur in circuits which are associated with valves to form amplifiers or detectors of some form or another and can be more suitably discussed under the heading of amplifier faults. The succeeding chapters deal with these matters at length, but it will be found that the basic methods mentioned here apply wherever questions of faulty tuning arise.

The chapter may be concluded with a reference to the band-pass tuner which is used in various forms to a considerable extent. In its simplest form this is merely an arrangement of two tuned circuits in cascade. Voltage is induced into the first, setting up a current which is a maximum at resonance. If this circuit is loosely coupled to a second circuit, voltages will be induced in this which will set up currents which can again be tuned to a maximum. The signal thus undergoes a double selection and with a loose-coupled arrangement the selectivity can be made of a very high order.

It will be clear that the currents in the secondary circuit can induce voltages back into the primary. A loose-coupled system is one in which the voltages so reflected back to the primary are negligible. This implies that the voltages induced by the primary are necessarily small and the output voltage across the secondary is only a fraction of that across the primary (about 50 per cent is the maximum before interaction becomes appreciable).

If the coupling is increased slightly, however, the effect is to produce two tuning points which become farther apart as the coupling is made stronger. If the circuits are so arranged that the peaks are a few kilocycles apart the effect is to maintain the output voltage fairly constant over a small band of frequency, and since any form of radio communication, and radio telephony in particular, requires such a band for its operation, this form of "band-pass" tuning circuit has become very popular.

The intermediate frequency circuits of a superheterodyne receiver are usually arranged with band-pass tuning which is simple to arrange, since such circuits operate at a fixed frequency so that the coupling and other constants of the circuit can be fixed at their correct optimum value. It is often found necessary, however, to use a similar form of circuit to couple the aerial to the first valve of the set, and since the aerial tune is variable it is necessary to use a double or "gang" condenser to tune both circuits together.

Band-Pass Tuner Faults. The method of transferring a small voltage from the first circuit to the second varies. Typical circuits are shown in Fig. 5.4. It is beyond the scope of this book to discuss the details of the design, which we must assume to be correct. The types of fault likely to be encountered are the same as for a single circuit, but their location may be more difficult.

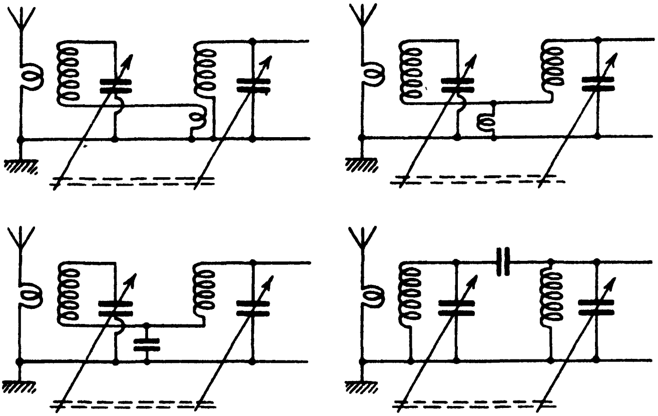

Fig. 5.4. Four Commonly Used Forms of Band-Pass Aerial Coupling.

If such a circuit fails to function input may be injected directly into the second circuit by connecting the signal generator to the top of condenser through a small capacitance. The output may be measured with a valve voltmeter or by using the set itself depending upon whether one is merely interested in obtaining a tune or wishes to make a definite measurement.

By using the same technique as for single circuits any fault may be located, and the input may then be transferred to the first circuit. If no output is obtained the first circuit is faulty or incorrectly ganged. If a valve voltmeter is being used the normal valve to which the circuit is connected should, of course, be disconnected, as otherwise the combined capacitance of the normal valve and the voltmeter valve will approximately double the stray circuit capacitance and the ganging of the two circuits must inevitably be disturbed. The behaviour of the first circuit may be examined by connecting the valve voltmeter across this circuit alone, ignoring the second circuit. If this test shows the circuit to be in order, then the fault lies in incorrect ganging.

The same sort of technique applies to the checking of an r.f. stage. The form of such circuits and the checking of the amplification is discussed in the next chapter, but the checking of the tuning and selectivity is effected in the same manner as for a band-pass circuit. The tuned circuit in the anode of the r.f. stage will be checked first by disconnecting the anode of the r.f. valve and injecting voltage from the signal generator either on to the top of the circuit through a small condenser or by using the primary winding as a coupling winding (if such is provided).

The aerial stage may then be checked, preferably by itself, and finally the two together. If both circuits, individually, are known to be in order, and if the valve has been found to be operating satisfactorily, and still the performance is poor, then the two circuits are not correctly ganged.

Adjustment of Ganging. The adjustment of the ganging of such circuits is important. Practically every receiver to-day contains at least two ganged circuits (apart from the oscillator circuit of superhet receivers, the adjustment of which is considered in Chapter VII), and it is essential to proceed systematically.

For two circuits to tune together it is necessary for three conditions to be satisfied. These are:

(1) The maximum value and the "swing" of the two sections of the condenser must be identical within close limits.
(2) The inductances of the coils must be the same.
(3) The stray capacitances in the circuits must be equal.

The first two requirements fall within the province of the designer, and careful tests are made on the components before assembly. The condensers are usually made with one or both of the end vanes having radial slots so that a portion of the plate may be bent closer to or farther away from the remainder and by bending the individual sections slightly the capacitances of the different sections may be matched very closely over the whole range of swing.

The coils are either matched by adjustment of the turns, either in number or position, or else they are provided with adjustable iron cores, the position of which is found to give the exact inductance and then sealed. Both these factors are beyond the control of the user or service engineer, so that service testing must be based on the assumption that requirements (1) and (2) have been fulfilled.

The third requirement is a variable factor. It cannot be completely allowed for in the design, particularly as the modern set with several ranges has to cater for quite different forms of coil with widely different self-capacitance. The usual practice, therefore, is to provide a small pre-set "trimmer" condenser across the coil. This has a maximum value of the order of 50 pF[1] and is adjusted about the middle of its range so that the stray capacitance of the coil and the rest of the circuit can be artificially increased to some fixed value. Small variations in circuit capacitance can thus be allowed for by a suitably different setting of the trimmer.

The adjustment is made when the circuits are assembled by actually tuning the circuits. The first test is to check the tune at or near the maximum of the main condenser with the trimmer set to the middle of its travel. Here the two circuits should line up without difficulty. If they do not, look around to see whether there is any large accidental capacitance of other obvious fault in the circuit. It will be something considerable, since a change of 20 to 30 pF in the capacitance across either circuit will have small effect at the top of the scale where the main condenser capacitance is between 500 and 600 pF.

If no obvious fault is found the condenser capacitances and coil inductances should be checked, using the methods given in Chapter XI. If the coil is of the semi-variable type, its inductance may be adjusted to suit.

Normally, however, it will be found that the two circuits tune together satisfactorily at the top of the scale. The condenser should then be set to a point near the bottom of its travel and the signal generator frequency readjusted until a signal is obtained. It may be necessary to increase the input to allow for possible lack of gang. Then readjust the trimmer condensers across the coils until maximum signal strength results. When this is obtained it should be possible to go through the tune *on each of the trimmers.*

If it is found that one trimmer gives a continually increasing strength as it is screwed in, it is possible that the correct tune has not been reached. Increase the setting of the *main* condenser *very slightly.* It should now be possible to reduce the trimmer setting and go through a proper tuning point. The other trimmer will also require to be reduced. A similar effect may occur if one trimmer does not reach its tune when "all out." Here the main condenser setting should be reduced slightly and a fresh attempt made. With a little practice a position should be found where both circuits can be tuned quite definitely on their trimmers.

When this happens it means that the stray capacitances have been equalised and the ganging should then hold satisfactorily over the rest of the scale. If no true tuning point can be found on both trimmers simultaneously, it indicates that the difference between the stray capacitances is greater than the range of the trimmer. It will then be necessary to add a small fixed condenser across the trimmer which already has the higher capacitance—i.e. the trimmer which is most screwed in. Such a condenser may be a small silver mica type of about 10 pF capacitance, or it may be made by twisting two lengths of insulated wire together—an inch or so will suffice. Such a condenser is illustrated in Fig. 5.5.

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[1] See footnote on p. 104.

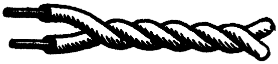

Fig. 5.5. Improvised Trimmer Made of Twisted Wire.

Adjacent Channel Selectivity. We may conclude this chapter with a brief reference to a type of tuning fault which arises from bad layout. The main reason for using two tuned circuits is to increase the selectivity and the most difficult circumstance with which the system has to contend is that of a weak station close in frequency to a much more powerful (unwanted) station.

Now any circuit will respond to a voltage impressed across it, even when it is not tuned, and the current produced by the powerful station may be of the same order as the maximum current we can obtain, even at resonance, from the much weaker wanted station.

We therefore pass the signals through another tuned circuit. This second circuit is subjected to voltages of the same order instead of in a ratio of hundreds to one, which permits the normal tuning properties of the second circuit to lift the wanted station clear of the interference. But this desirable condition will be largely frustrated if by any means the current in the first circuit is allowed to pass into the second circuit, because this will leave us with currents still of the same order whereas the double-filtering action should have made the wanted current several times stronger than the interference.

Long earth leads are a fruitful source of this trouble, both in band-pass r.f. circuits and in the i.f. stages of superhets. The amount of lead may be quite small and it may only pass on a fraction of the current. Yet it may be enough to destroy an otherwise good performance, while as explained in Chapter VII, this form of coupling is a prolific source of "birdies"—the unwanted and elusive whistles to be found in a poor superhet.

CHAPTER VI

RADIO-FREQUENCY TESTING

MODERN conditions call for some amplification prior to the detector. In the majority of sets this amplification is obtained by the use of an amplifier operating at a fixed frequency, the incoming signal being changed in frequency to conform to the requirements. This is known as a superheterodyne receiver and a separate chapter is devoted to such circuits.

Even with superhets, however, there is often one stage of amplification at the frequency of the incoming signal, while one occasionally encounters receivers in which all the r.f. amplification is carried out at the signal frequency. Such sets are known as "straight" sets.

Principles of R.F. Amplification. It is desirable, therefore, to consider briefly the basic principles of radio-frequency amplification. A typical single stage is illustrated in Fig. 6.1. The aerial is coupled to the input circuit by conventional methods, usually by means of a separate coupling coil, though sometimes a tap on the secondary coil is used. The voltage developed across the tuned circuit is applied to the grid of the r.f. valve.

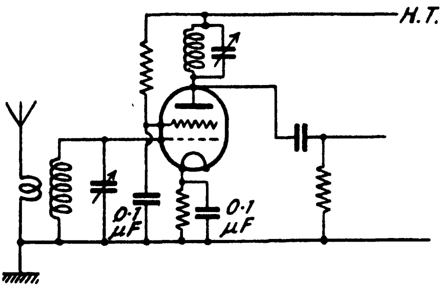

Fig. 6.1. Basic Circuit of Tuned r.f. Amplifier.

As with any valve amplifier, it is necessary to arrange some impedance in the anode circuit across which the varying currents generated by the applied grid voltage can develop amplified voltages. Except in special circumstances, a resistance is unsuitable for this purpose because the reactance of the stray capacitances is much smaller than the resistance. For instance, a capacitance of 25 pF[1] at a frequency of 1 Mc/s is only 6,400 ohms. This would seriously reduce the effective anode impedance and the shunting action would become progressively worse as the frequency increased.

The usual arrangement, therefore, is to employ a tuned circuit for the anode impedance. Any stray capacitance then adds to the tuning capacitance and serves a useful purpose. This arrangement has the further advantage that it increases the selection of the wanted signal, and in many cases the circuits are designed from this stand-point, the stage gain being appreciably less than the maximum to permit of greater selectivity.

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[1] The letters pF stand for picofarad which is one-millionth of a microfarad. The letters μμF, denoting micro-micro-farad are sometimes used for the same quantity.

Screening. It was mentioned in the chapter on a.f. amplifiers that any coupling between output and input circuits is to be avoided. If the feedback is positive the signal strength is increased and will usually culminate in continuous oscillation. If the feedback is negative the signal strength will be decreased.

At radio frequencies voltage can be fed back through channels which would be quite negligible at lower frequencies. Two coils several inches apart may have sufficient coupling between them to provide appreciable feedback, while it has already been shown that quite small capacitances exhibit relatively low reactance at radio frequencies.

Radio-frequency circuits, therefore, are screened from one another. The coils and much of the associated circuits are enclosed in metal boxes, usually of aluminium or copper. The effect of this is to eliminate capacitance coupling between the circuits because any capacitance currents which flow will pass to the screen, which is connected to earth, and hence, although they may cause some loss of energy, they cannot induce voltages into other parts of the circuit.

If the screen constitutes a complete box or can it will also greatly reduce any magnetic coupling. The magnetic field of the coil induces "eddy currents" in the screen, and these currents in turn produce magnetic fields which are in the opposite direction to the original fields. Outside the screen, therefore, the effective magnetic field is practically zero.

One of the sources of trouble in r.f. amplifiers is feedback due to inadequate screening. If more than one stage is involved a very small stray capacitance in the wrong place may result in complete instability. More often it only produces a reaction effect, the signal strength being increased several times, but being short of the actual oscillation point. At first this might seem a good fault, but actually it is bad because the behaviour of the circuit under these conditions is entirely dependent on small changes in the performance of the valves. Even a change in the weather may alter the value of the stray capacitance slightly and hence the performance of the set.

Screened Valves. Screening of the circuits is not enough. There is appreciable capacitance between the anode and grid of the valve itself, and this produces serious feedback. All modern sets, therefore, use screened valves in which a gauze screen or grid connected to earth is interposed inside the valve between anode and grid. Actually the screen is connected to a steady positive potential usually between 80 and 250 volts, depending on the type of valve, and this results in a valve having very useful properties for r.f. purposes.

The amplification factor is greatly increased and the internal a.c. resistance of the valve becomes of the order of megohms. We have seen that any resistance connected across a tuned circuit introduces losses which reduce its *Q*. With a triode valve, which usually has an internal resistance less than 100,000 ohms, this loss is serious, but with a screened valve the effect is small.

It can be made still smaller by using a tapped anode circuit or an r.f. transformer, as in Fig. 6.2, and this form of circuit is often used because with modern valves it is possible to obtain more gain from a stage than is actually required, so that we can afford to throw gain away to increase selectivity.

If the external anode impedance is small compared with that of the valve the amplification obtained from the stage is *gZ*, where *g* is the mutual conductance of the valve in mA/v and *Z* is the anode impedance in kilohms (thousands of ohms). In the great majority of circuits this assumption is justifiable so that the calculation of stage gain is a comparatively simple matter. Remembering that a tuned circuit looks like a high resistance of value *L*/*CR*, we can quickly estimate *Z*.

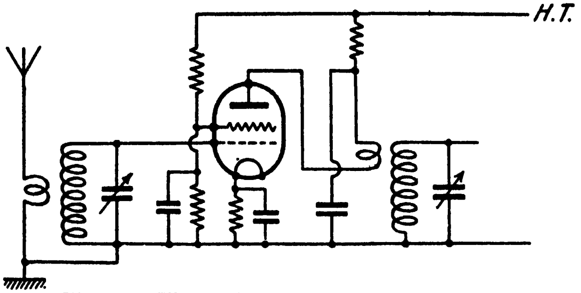


Fig. 6.2. Illustrating use of r.f. Transformer.

Assuming a coil of 200 μH inductance tuned with a condenser of 200 pF and a resistance of 7 ohms, the dynamic resistance is 143,000 ohms. If we use this circuit with a valve having a "slope" of 2mA/v the gain is 286. Such a gain is quite possible though usually a smaller value obtains. The important term is the resistance, which of course is the r.f. resistance and not the d.c. resistance, and it must also include any losses introduced by other parts of the circuit. The total effective resistance in the circuit might well be twice that of the coil alone which would reduce the gain to about half the figure quoted.

As a rough guide it may be taken that the r.f. resistance is likely to be at least four times the d.c. resistance when everything is taken into account. Another angle is to estimate the *Q* of the coil. The coils used in the average radio set have *Q*'s of the order of 60 to 75, rising to perhaps 150 with iron-cored coils and high grade components in the remainder of the circuit. The expression L/CR may be written $Q/\sqrt{(L/C)}$. If we assume a *Q* of 70 with the same values of *L* and *C* as before the dynamic impedance is

70,000 ohms, giving a stage gain of 140, which is the sort of figure likely to be encountered in practice.

Factors Affecting Gain. It will be seen that the stage gain is determined by the quality of the circuit and by the value of *g*. The quality of circuit is determined by the designer and is not likely to alter seriously in use except from some cause such as a bad switch contacts or faulty components. In some sets the tuned circuit actually includes a by-pass condenser, as, for instance, in the arrangement of Fig. 6.3. If this condenser is defective the circuit will suffer, but it is more likely that any such fault will produce complete failure which is readily located.

More difficulty is likely to be experienced with change in valve performance, causing an alteration of the slope *g*. Changes in anode voltage have very little effect and may be ignored, provided that there is reasonable voltage available. A change in screen voltage has more effect, particularly if it is too low. The recommended operating voltage for the valve can be ascertained from the makers' figures.

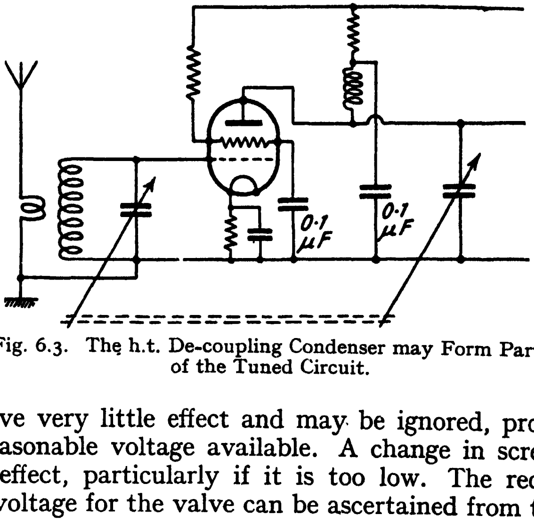


Fig. 6.3. The h.t. De-coupling Condenser may Form Part of the Tuned Circuit.

The most important factor is the voltage on the grid. As this becomes more negative the value of *g* falls off sharply. It is therefore necessary to check the value of grid bias and see that this is of the right order.

The possibility of varying the gain in this manner is made use of as a method of gain control. The valve is made with a specially-graded grid structure in consequence of which the falling off in slope as the bias increases is more gradual and a smooth control of the gain can be obtained by altering the value of steady bias. Such valves are known as vari-mu types, and are extensively used.

Measurement of Stage Gain. Clearly one of the most useful things which we can check in an r.f. circuit is the stage gain. Let us consider how to do this. The first step is to connect a valve voltmeter across the output of the stage and supply a suitable input from a signal generator. If we are concerned with the gain of the valve alone, we should dispense with the dummy aerial and connect the output of the attenuator direct to the grid of the valve in question. The outer conductor of the feed cable (or earth terminal) must of course be connected to the earthy side of the set to complete the circuit. By adjusting the setting of the attenuator to give a suitable reading on the valve voltmeter, we can then determine the input voltage necessary for a given output volts and so obtain the stage gain by simple division. No modulation is required.

Two points may be noted here. In the first place, the connection of the valve voltmeter across the output will alter the tune of the anode circuit. Therefore, it may be necessary to retune the set. The second point is that the connection of the grid of the valve direct to earth through the attenuator may in some cases cause trouble, as, for example, with a universal or d.c. receiver where the chassis or earth line of the set is not directly in contact with earth as already explained in Chapter VIII. To avoid trouble, therefore, the output from the attenuator of the signal generator should be connected to the grid through a small isolating condenser.

In most cases the output circuit across which the valve voltmeter is connected will also be connected to a valve in the receiver. Whether this valve is left in place or not depends upon the information desired. If one is examining the performance of the amplifying valve alone then the subsequent valve could be removed. If one is concerned with the behaviour of the whole stage in the receiver then the subsequent valve should be left in position because the damping due to this valve, if any, will then be allowed to operate. The valve voltmeter, of course, should introduce negligible damping into the circuit and if it is properly constructed it will do so.

Any of the stages in the set may be examined in this way, and, if necessary, two or more stages in cascade can be examined by leaving the valve voltmeter across the detector stage and introducing the input progressively farther back. In place of a valve voltmeter an oscilloscope may be used provided it is calibrated so that a given deflection corresponds to a known input voltage.

Fault Conditions. If the gain is shown, by such a test, to be of the right order, well and good. If not, there are three possibilities to consider, viz.:

1. The circuit refuses to function at all.
2. The performance is inadequate.
3. The circuit is unstable. When the circuits are brought into tune, the arrangement bursts into oscillation.

Let us consider the case of failure to function. As a general rule one can obtain some idea of the location of the trouble by the behaviour of the circuit. It is often found, for example, that one circuit appears to tune satisfactorily, whereas the other does not, which localises the defective portion.

If it is the anode circuit which is at fault connect the input to a suitable point—either the grid end of the secondary or disconnect the lead from the r.f. anode and use the primary as a coupling winding. Since the circuits are at h.t. potential the input *must* be isolated by connecting it through a small condenser.

The tuning circuit itself may then be examined for faults in the manner already described in the last chapter. By analysing the circuit in the manner outlined therein, the cause of the difficulty may be located and remedied.

If the anode circuit in the detector stage is in order, or if we have located and corrected a fault therein, the r.f. valve may be re-inserted and connected up. It is assumed, of course, that the valve has been tested in accordance with the data already given (see Chapter II). The re-insertion of the r.f. valve completes the whole circuit, but it is as well to test the tuning of the detector stage once again, in order to ensure that the mere connection of the r.f. valve into position has not introduced some difficulty. Such things can happen owing to faulty valve holders or wires short circuiting or something of this nature. Such faults are not usual, but they *are* experienced and are all the more bothering when they are encountered. Hence it is as well not to take anything for granted, but to make quite sure that the mere act of inserting the r.f. valve has not re-introduced the trouble.

Assuming, however, that this is not the case, we can now turn our attention to the input circuit. It is advisable to tune the anode circuit to some particular signal, and then endeavour to tune the aerial circuit to the same signal. This it should do quite satisfactorily, but if it does not, then either the tuning circuit itself is at fault or the valve is not working.

It is not difficult to check the valve. If the signal generator is connected to the grid of the valve a substantial voltage may be applied independently of the tuning circuit. It is, indeed, desirable to disconnect the tuned circuit from the grid temporarily to avoid any difficulty. For example, the circuit may have a short circuit across it which would reduce the output from the signal generator to zero.

Hence, remove any unwanted portions of the circuit and connect the signal generator to the grid. If an isolating condenser (or the dummy aerial) is still in circuit, see that there is a suitable leak from grid to cathode or bias point so that the operating conditions of the valve are not disturbed.

With an input of 0·1 volt the anode voltage should be between 10 and 20 volts with a normal stage, corresponding to a gain between 100 and 200. If no output is obtained check the voltages at the various points, including screen volts and grid bias. If the valve is an r.f. pentode, see that the suppressor is correctly connected. Simple reasoning on the lines already defined will locate the fault and a remedy may be applied.

If the valve *is* working the fault lies in the tuning circuit and may be located by the methods described in the last chapter.

Inadequate Performance. The case where the valve gives a low gain is more troublesome. The valve itself may be at fault, and it should be checked or replaced.

The voltages on screen and grid should be checked, and if these are in order the by-pass condensers should be examined. The screen of Fig. 6.1, for example, is fed from the h.t. line through a resistance which drops enough voltage to bring the screen potential correct *under steady conditions*. When the valve is operating, however, the current in it will vary and if the screen is not "tied down" the screen current will vary, causing the screen voltage to vary in a manner which will reduce the gain. The function of the condenser from screen to earth is to prevent the variation and it should be checked that this condenser is not faulty and that it is of adequate capacity. The usual value is 0·1 μF, but more may be desirable. Sometimes an electrolytic condenser is used, and this may develop, in time, a high resistance at radio frequencies. A paper condenser of 0·1 μF in parallel will remedy any trouble on this score.

The cathode by-pass condenser must also be checked, since if this is open circuit or has a high resistance, the gain of the stage will be seriously reduced because of the negative feedback introduced, as explained in Chapter IV (see Appendix III).

High-Frequency Losses. It is of interest to note here some of the numerous defects which may exist in components intended for high-frequency work. The principal offender is the tuning condenser, which is usually assumed to have negligible resistance. This is not by any means the case, and condensers have been known to have resistances more than that of the coil. A good quality condenser introduces no serious loss, but if the condensers are not known to be satisfactory it is advisable to replace them with a proved make.

Bakelised-paper dielectric introduces considerable loss, the resistance of condensers of this type being two or three times that of the coil (10 to 20 ohms or more, at 400 metres). Similar losses may occur in valve holders, coil-formers and other portions of the insulation.

Bad switch contacts, faulty pigtail connections, etc., may all give rise to trouble, while finally there is the coil itself. Usually this is of a proprietary type and is thus considered above suspicion. If any doubt arises, replace the coil with a simple type of construction, known to be efficient. Do not forget that metal objects near to a coil may introduce considerable loss into the circuit.

Another source of trouble is a leak across the circuit. This will reduce the efficiency of the circuit, possibly quite seriously. Such a leak may be due to a bad insulator, which is satisfactory for d.c., but has serious high-frequency losses.

Instability. We now come to consideration of the third form of trouble in high-frequency circuits, that of instability. It has been explained that any inter-action between the anode and grid circuits will produce a reaction effect, tending either to increase or decrease the effective amplification according to the direction of the feedback.

The use of screened valves and the enclosure of the circuits in screening boxes removes most of the stray coupling, but it is still possible for coupling to exist between portions of the circuit which are outside the screens, particularly with more than one stage. Care must be taken, therefore, to see that all leads are located close to their own portion of the circuit; if necessary, any "hot" leads may be enclosed in a metal tube for some part of their length. For this purpose loose metal braiding is usually employed slipped over the insulation on the wire. This increases the capacitance to earth of the particular lead, and therefore must be used sparingly, for it will increase the minimum capacitance of the tuning condenser and may disturb the ganging of the circuit, while the losses due to the capacitance current flowing from the wire through the insulation to the earth screen may be quite appreciable and give rise to serious reduction in the performance.

Earthing. A further difficulty arises in the matter of the earthing of the receiver. Circulating currents flow from the coils to the earth screen around them and find their way to the point of lowest potential in the circuit. With modern metal chassis construction there may be some difficulty in deciding which is the point of lowest potential. It is unsatisfactory to regard the whole chassis as an earth point, for the impedance of the metal is quite appreciable, and there will be only one point on the chassis which is really at earth potential.

This question is really one of design, but it can be stated that for best results all earth points should be taken to one specified point on the chassis, preferably the earth terminal. This often involves the running of a lead between two points which are already apparently connected through the chassis. The fact is that the direct route through a piece of heavy gauge wire is of lower impedance than the path through the metal-work of the chassis and the current will prefer to take this shorter route.

Again, if instability is being experienced it often pays to return the earthy or low potential end of the various circuits direct to this earth point on the chassis through a piece of stout wire, rather than connect them direct to the chassis at the most convenient point. It is useful to run an earth busbar around the chassis, connecting this busbar to the earth terminal and running it in such a way that short leads can be taken to it from each of the various earth points on the tuned circuits (both coil and condenser connections).

Circulating currents will also cause difficulty if two or more coils are included within the same screening box. Even though a separator be arranged inside the screening box so that it is apparently split up into two compartments, the continuous metal path along the top, bottom and sides enables the circulating currents set up by one circuit to interact with the other and produce instability. The only safe procedure is to enclose each coil in its own entirely separate screening compartment.

It is impracticable to dwell on this aspect of the subject in greater detail here. The matter is discussed further in Chapter VII dealing with superheterodyne receivers, many of the remarks in which will apply with equal force to ordinary tuned radio-frequency circuits. Instability arising from de-coupling in the grid circuit where a.v.c. systems are in use is also mentioned in Chapter VII.

Generally speaking, however, the stability of the circuit will have been secured by the original designer, so that these problems do not ordinarily come within the heading of faults. It is, however, conceivable that an earth connection on a particular chassis may have become defective or broken so that the earth return currents are forced to take an unusual route, thereby rendering the receiver unstable.

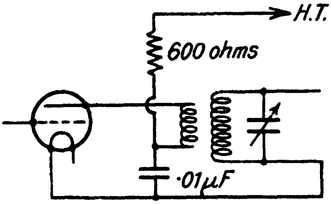


Fig. 6.4. Illustrating R.F. Filter.

De-coupling. The possibility of feedback through the common impedance of the h.t. supply circuit has already been mentioned in Chapter IV. This possibility is equally present in r.f. circuits and may give rise to instability or loss of gain, according to the direction of the feedback.

The remedy is to isolate the circuit in the same way as is done in the low-frequency case. In the r.f. case, however, owing to the much higher frequency of the current, it is only necessary to use comparatively small resistances, and a circuit such as that shown in Fig. 6.4 will be quite effective in many cases.

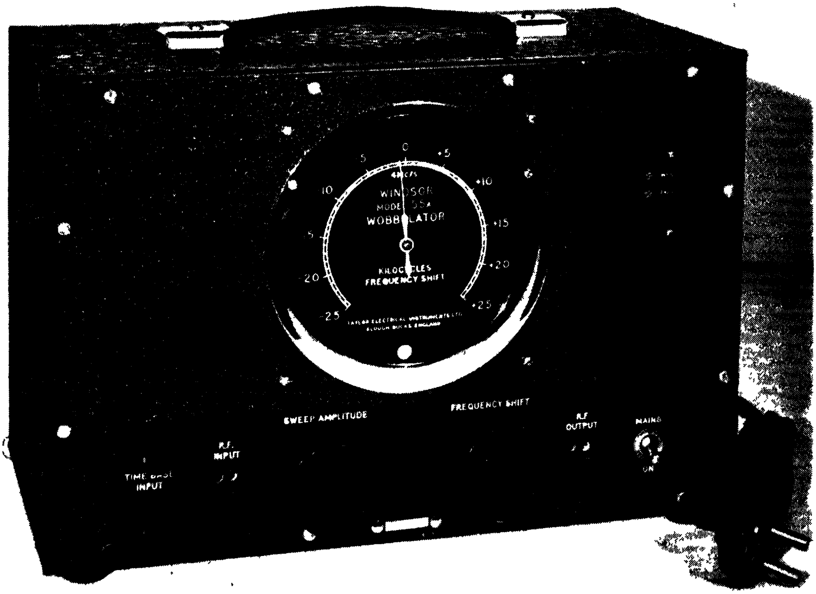
An alternative method is to use a high-frequency choke in place of a resistance. This method may be more effective than the resistance-filtered system where the circuit having a very high amplification is being employed.

By-passing. In many cases the introduction of a complete filter circuit in this manner is not necessary. The connection of a suitable by-pass condenser across the high-tension supply will often cure the trouble. This condenser, however, should be connected as near as possible to the actual point on the tuning circuit at which the high tension voltage is introduced. Fig. 6.5 illustrates, for example, a typical layout, and the proper place for a condenser is across the point marked *X* and *Y*. The connection of a condenser across points marked *BC* would not be so good, because there is a considerable length of lead having appreciable inductance still left in the circuit. Moreover, the current flowing in these leads is capable of inducing voltages into other parts of the circuit and causing instability by

PLATE IX

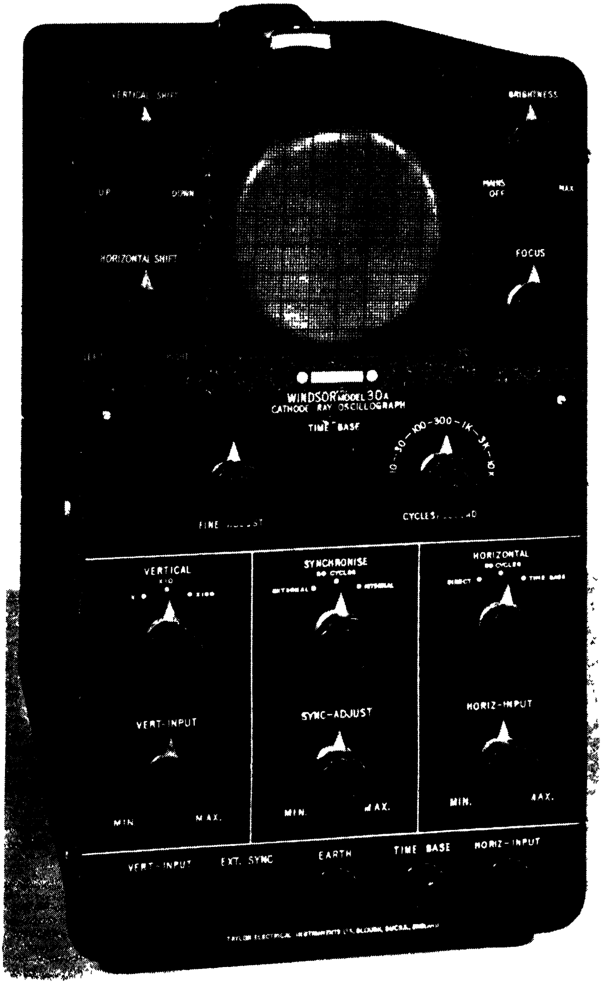
The Avo Signal Generator here is a compact service oscillator covering all r.f. and i.f. frequencies in six ranges. It has a built-in attenuator going down to 1 microvolt. The device in the foreground is an artificial aerial to simulate the effect of the actual aerial.

PLATE X



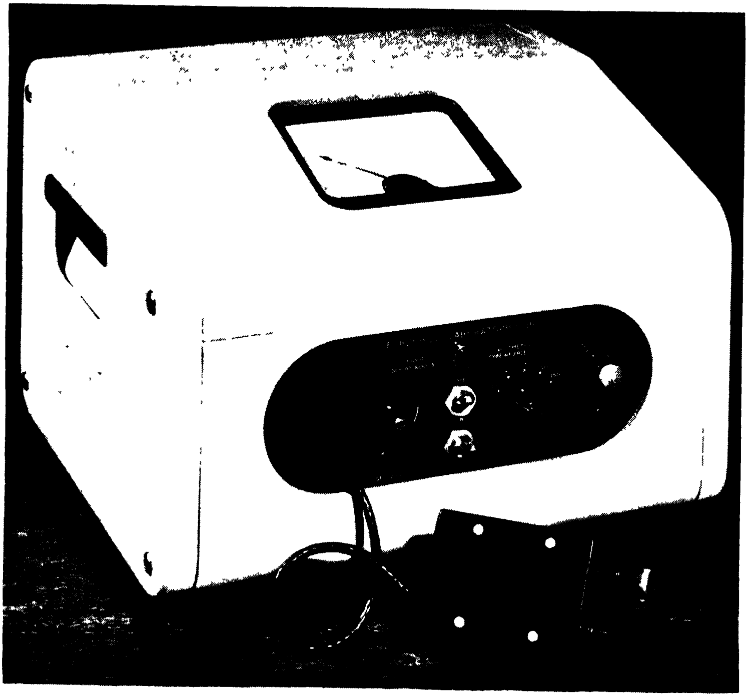
This Taylor Wobbulator is designed for use with an oscilloscope and signal generator to provide a variable-frequency scan for lining up receivers.

PLATE XI



This Taylor Oscilloscope is designed for audio-frequency examinations and may be used with the wobbulator (Plate X) for showing resonance curves on the screen.

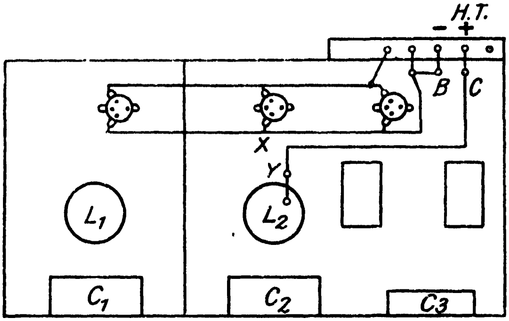
PLATE XII



This is a diode voltmeter by Furzehill Laboratories. The diode is housed in the probe in the foreground so that it may be located close to the point of test. The signals then pass down the cable and are recorded on the meter.

this means. In modern high-efficiency receivers it is often necessary to by-pass each circuit individually to ensure that no wire, however short, carries high-frequency currents from any circuit other than its own.

Measurement of Selectivity. The second quantity on which we require information is that of the selectivity—the amount by which the set, or its individual circuits, cuts down the amplification as the frequency varies from the resonant value. For this purpose, also, no modulation is necessary, the r.f. oscillations being constant in amplitude. A valve voltmeter is connected across the grid and filament of the detector valve, or across the particular circuit arrangement under test. When the circuit is tuned to resonance with the oscillator, the deflection is, of course, a maximum, and on either side of the resonance the strength falls off.



6.5. The By-pass Condenser should be Connected Across *X* and *Y*.

The selectivity may clearly be estimated by mistuning the oscillator on either side of the resonant point, noting the reading on the valve voltmeter for various frequencies. In this way a resonance curve can be plotted.

This method, however, is of limited application, for the valve voltmeter will not cover a variation of more than about 10 to 1, while the selectivity of a single circuit may be several hundred, 20 or 30 kc/s. off resonance. The usual practice, therefore, is to mistune the oscillator, as before, leaving the receiver circuit tuned to resonance, but to increase the input from the signal-generator each time until the reading on the valve voltmeter is the same as before. This gives an inverted selectivity curve which is just as helpful and can be carried to much greater lengths, the oscillator being mistuned, if necessary, until the signal is several hundred times stronger than normal, so that the response is so many hundred times down at this point.

We can either plot a complete resonance curve, as shown in Fig. 6.6, or note the "times down" at, say, ±5 kc/s. and ±20 kc/s.

off tune. The subject is discussed further in Chapter XII dealing with the testing of complete receivers.

Here again the use of an oscilloscope is possible in place of the valve voltmeter. It is not even necessary to calibrate it since the indication is kept the same throughout the test.

Distortion. Distortion is not a factor of primary importance in an r.f. amplifier. The function of the r.f. oscillations is to act as a carrier, the amplitude being varied at the modulation frequency. If the carrier wave is distorted the effect is not serious provided it is not too great, and 10 to 15 per cent is quite tolerable.

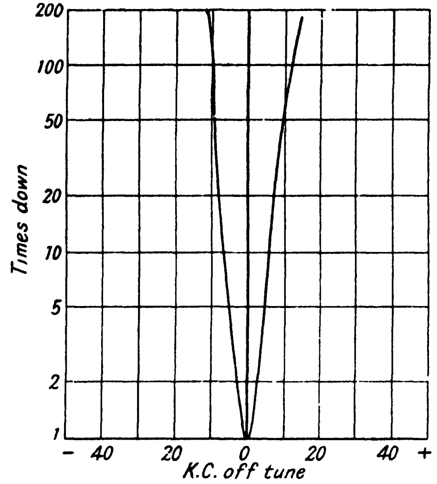


Fig. 6.6. Typical "Inverted" Resonance Curve on an I.F. Amplifier.

Clearly, if the valve is operating in a limiting condition so that the strength of the signal cannot increase to the full extent, full modulation cannot be obtained and the reproduction will lack contrast. If it is desired to check this aspect, an oscilloscope should be connected across the tuned circuit under examination and the input varied over the full range which it will be called upon to deliver in practice. The output should vary correspondingly and in a linear manner. If it does not the valve is operating incorrectly, possibly due to ageing or maybe to incorrect design.

The time base may be run at an audio frequency showing a band pattern. Any serious distortion of the r.f. waveform will appear as one or more bright horizontal lines across the screen.

Detector Tests. The link between the r.f. and a.f. stages is the detector or demodulator. This important stage has to handle both types of current and thus has a vital influence on the performance of the whole receiver.

Most modern receivers use a diode detector, and as this is also the most simple we will consider its operation first. Fig. 6.7 shows two forms of a series diode circuit. The voltage developed across the tuned circuit is applied across the diode in series with a resistance *R* shunted by a condenser *C*. When the point *A* is positive, current flows through the diode and charges up the condenser *C*. This charge then leaks away through the resistance, but if the value of *R* is large only a fraction of the charge leaks away before the point *A* has again become positive, so that the loss is made good.

The diode will only conduct when its anode is positive. The current into the condenser makes the cathode positive, so that if *R* were infinite the condenser would acquire a charge equal to the peak value of the applied r.f. voltage and thereafter the diode would never conduct because its anode would never be raised to a higher potential than the cathode. In practice the leakage of charge through *R* causes the voltage on the condenser to fall slightly, and then during the next positive half cycle as soon as the voltage of the point *A* exceeds that on the condenser current flows through the diode and replenishes the charge. The action is similar to that of the single-wave rectifier discussed in Chapter VIII.

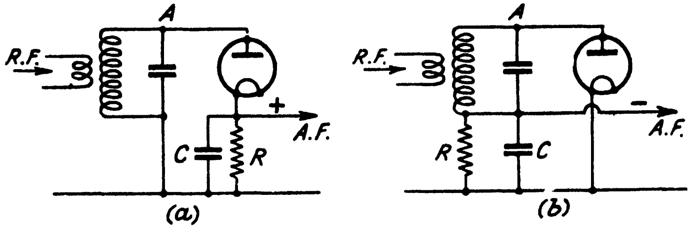


Fig. 6.7. Alternative Forms of Series Diode Detector Circuit.

The "time constant" of the resistance condenser combination must be chosen so that while the charge has little opportunity to leak away during the short time between the positive peaks of the r.f., it will follow the much slower variations in the amplitude of the r.f. due to the modulation. The result is that the voltage on the condenser builds up to a value approaching the peak value of the r.f. (about 85 per cent thereof in practice), and if this peak value changes due to the modulation of the carrier wave, the voltage on the condenser follows the changes faithfully. For this to be fulfilled the product *CR* should not exceed $1/4f$, where f is the highest *modulation* frequency to be handled.[1]

---

[1] The condenser must discharge through the resistance more rapidly than the fastest change in amplitude of the r.f. carrier. The condenser discharges exponentially to 1 per cent of its original voltage in a time equal to 5CR seconds. This time must not exceed the time taken for the amplitude of the carrier to change from maximum to minimum at the highest modulation frequency, which is half a cycle. Hence $5CR = 1/2f$ and $CR = 1/10f$.

Actually, however, the condenser will discharge to 13.5 per cent of its initial value in a time 2CR, and since most transmissions only modulate to a depth of a little over 80 per cent this will suffice. On this basis CR need only equal $1/4f$.

The subject is discussed at length in Appendix I.

The condenser *C* absorbs all the r.f., leaving only the a.f. component to be passed on to the output stage. The difference between the two forms of circuit is simply in the direction of the steady voltage produced. Usually this is removed by including a condenser, as shown in Fig. 6.9, but when developing a.v.c. voltage the steady voltage is utilised, and since a negative voltage is usually required the circuit of Fig. 6.7 (*b*) is used.

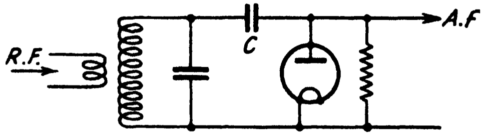


Fig. 6.8. Parallel Diode-Detector Circuit.

Fig. 6.8 shows a parallel diode. Here the r.f. voltage is applied to the condenser through the diode as before, but the leak is shunted across the diode and operates during the period when the diode is non-conducting. In other respects the action is the same as with the series form of circuit.

The arrangement is not fully efficient because of the slight leakage which takes place during the r.f. cycle and also because the diode itself has some internal resistance, but in practice efficiencies between 80 and 90 per cent are obtained. This is a matter which sometimes has to be checked, and this may be done by measuring the r.f. voltage applied (with a valve voltmeter or similar device) and noting the steady d.c. potential developed across the output. This output voltage cannot be measured by any ordinary voltmeter, which would have a resistance far lower than the resistance *R* and the most convenient method is to insert a microammeter in series with *R*. The voltage across *R* is then simply *IR*, *I* being the observed current and *R* the resistance.

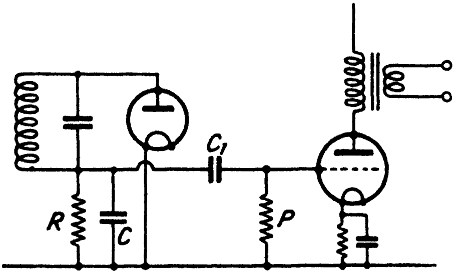


Fig. 6.9. The d.c. Component across *R* is removed by C_1.

Diode Distortion. The diode itself is a substantially perfect detector from the viewpoint of distortion, provided that the time constant of the circuit is correct. It is usual, however, to couple the diode to the output stage through a condenser, as in Fig. 6.9, to remove the d.c. component of the voltage. When this is done serious distortion is likely to be introduced unless the grid leak *P* is large compared with *R*. The effect is only troublesome on high modulation depths, and it was shown on page 82 that the maximum depth of modulation which can be obtained without distortion is $P/(P+R)$.[1] If P is four times R, modulation up to 80 per cent is possible. The value of C_1 must be chosen in relation to P to satisfy the customary low-frequency requirements as explained in Chapter IV.

The faults likely to occur in a diode circuit are complete failure, reduced efficiency and distortion, all of which can readily be located if the foregoing treatment has been understood.

Grid Detectors. A modification of the diode circuit is the grid detector shown in Fig. 6.10. This form of circuit indeed was used for many years before the diode came into its own. Actually, it is simply a combination of a diode and a triode amplifier. The grid and cathode of the valve act as a parallel diode, as in Fig. 6.8, and the voltage developed across the resistance then produces changes in anode current.

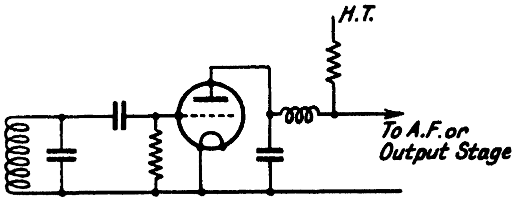


Fig. 6.10. The Grid Detector combines the action of a Parallel Diode and an a.f. Amplifier.

The arrangement has two major disadvantages. The charge acquired by the grid condenser is negative, so that the anode current is reduced. Hence the operating point on the valve characteristic shifts downwards and with a strong signal the anode current is reduced to cut off so that the output limits. Hence the system can only be used on small inputs, but within this limitation it is very sensitive. The other limitation is that there is no separation of the r.f. The grid is subject to r.f. as well as a.f. voltages, so that r.f. currents appear in the anode circuit where they may cause trouble unless they are filtered out.

Even though the valve may be a poor r.f. amplifier the modulation voltage which we require is normally only a small fraction of the carrier voltage, so that we may easily have as much r.f. as a.f. in the anode circuit, and this will be passed on to the next stage. The effects of r.f. in the a.f. stages have been discussed in Chapter IV and need not be repeated here. To avoid these troubles the anode of the detector valve must be by-passed with a suitable condenser which tends to destroy the response of the circuit to the higher audio frequencies. The inclusion of an r.f. choke in series with the anode resistance will minimise this trouble. The choke should have an inductance such that its reactance at the upper frequencies is four or five times as great as the anode resistance, and its self-capacitance should be kept as low as possible.

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[1] See also *Modern Radio Communication*, Vol. II, Chapter VI.

Detector Bias. There is no bias on the detector valve of Fig. 6.10. This is quite correct, and no bias should be used or the grid will not begin to operate as a diode until a certain strength of signal is reached which will give most peculiar quality. Sometimes a small *positive* bias is used, particularly with battery sets where the leak is often taken to the positive leg of the filament. This is because the current which flows in a diode is not proportional to the voltage at very small values of applied voltage. There is a "knee" in the characteristic exactly as with any form of thermionic device. Hence the action is not linear, and, moreover, it is much less efficient because of the greatly increased effective resistance of the diode. The application of a small permanent positive potential to the anode overcomes this defect, and improves both the signal strength and the quality.

Faults in grid detectors are similar to those which occur with diodes, plus the added possibilities of overloading and r.f. in the anode circuit.

R.F. Chokes The action of r.f. chokes has already been referred to on page 75. An r.f. choke is usually regarded as an inductance, and shown as such in circuit diagrams. However, it is impracticable to wind a coil which has a high *inductive* reactance, both at r.f. and high audio frequencies. To be effective at a.f. a large number of turns is required, and this involves a high self-capacitance. This self-capacitance will resonate with the inductance at some point, and if this can be arranged to occur just beyond the upper audio-frequency limit, the choke then behaves at all frequencies above its resonant point as if it were a capacitance (equal to the self-capacitance).

If this capacitance is kept small—a few pF only—the capacitive reactance is very high—of the order of 0·1 megohm even at 1 Mc/s, so that we fulfil both the essential requirements. It should be remembered that a choke must always have a by-pass on the r.f. side so that a true filter action results—a high series impedance in the path where we do *not* want the current to flow and an easy shunt path to earth.

Anode Bend Detectors. One occasionally encounters the anode-bend detector, an arrangement based on the curvature of the I_aE_g characteristic of a valve. This system, however, is now virtually obsolete. It is discussed briefly on page 79.

A.V.C. Circuits. The diode detector is often used to provide a voltage proportional to the strength of the carrier, which in turn applies bias to the r.f. stages. If the carrier increases, more bias is automatically applied which reduces the gain until the level is restored, and similarly with a reduction.

Typical circuits will be found in the next chapter. The action of permits the number of tuned circuits to be increased so that there is some added complexity on this account, but with logical reasoning faults may be located quite simply.

I.F. Transformers. To make full use of the possibilities the couplings in the i.f. amplifier are made in the form of double wound transformers having both windings tuned. It was explained in the chapter on tuning tests that with two tuned circuits in cascade a marked improvement in selectivity was possible. The form of circuit is illustrated in Fig. 7.1 while Fig. 7.2 shows the influence of the coupling on the results.

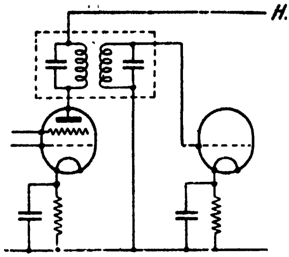

Fig. 7.1. Modern Superhets use Band-Pass I.F. Transformers.

Coupling is the term used to denote the energy transfer from the primary to the secondary. Ideally we should transfer just enough energy from the primary to make up for the secondary losses. With this "critical" coupling the voltage developed by the secondary is a maximum and is of the same order as that developed by the primary.

If less than critical coupling is used the secondary does not develop its full voltage and as there is no appreciable improvement in the sharpness of the resonance curve an under-coupled circuit is merely an inefficient arrangement. If the circuits are over-coupled the secondary cannot use all the energy it receives and transfers some of it back to the primary. The effect is to mistune the primary which then develops its maximum voltage at *two* points one on either side of the true tuning point. As the coupling is still further increased the secondary also develops this double-humped tuning curve. The effect will be clear from Fig. 7.2.

Now a slight flattening of the top of the resonance curve is an advantage because, as is well known, a modulated r.f. transmission does not occur at a single frequency but occupies a band of frequencies, this band being between 10 and 20 kc/s wide for normal telephony. If we could arrange to accept all frequencies within a small band around the resonance point with equal strength and then cut off sharply we should obtain a resonance curve very suited to the requirements. A transformer having two windings critically coupled or slightly overcoupled fulfils these requirements and i.f. transformers are designed on this basis. The coupling is adjusted by the designer by placing the coils at the appropriate distance. The coupling is not purely inductive since some energy will be transferred through stray capacitances and the designer has to take all such effects into account. Except in special cases, however, the coupling is fixed and cannot be altered subsequently.

The exception is the variable selectivity transformer in which some arrangement is made, either mechanically or electrically, to vary the coupling within certain limits so that various forms of tuning curve may be obtained from under-coupled to over-coupled. Such circuits are not common, however, and where they are encountered the makers usually issue special instructions for their alignment.

It will be clear, however, that the adjustment of the tuning of even a normal i.f. transformer is not easy because the tune of the primary affects the secondary and vice versa. The most satisfactory method is by the use of a frequency modulator and cathode ray tube, as explained in Chapter XII, but alternative methods are given later in this chapter.

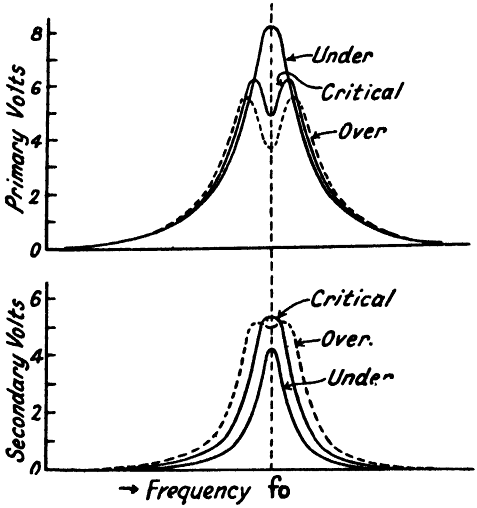

Fig. 7.2. Primary and Secondary Resonance Curves of Tuned Transformer.

Conversion Gain. Both the i.f. valves proper and the frequency changer are provided with transformers of this "band-pass" type, and when testing a superhet we can consider the i.f. amplifier to commence at the grid of the frequency changer. We can measure the gain of the i.f. stages by normal methods (and a detailed description is given later), and if we apply input at the intermediate frequency to the grid of the frequency changer it will also behave as an i.f. amplifier.

A further test is then necessary to determine the behaviour of the stage as a frequency changer. For this purpose we apply *signal* frequency to the grid and adjust the frequency of the local oscillator to the correct value when voltage (at the intermediate frequency) will appear in the anode circuit. The ratio of i.f. output voltage to r.f. signal input is called the *conversion gain* of the stage. It is appreciably less than the gain of the stage as an i.f. amplifier—usually about half. We shall see later how best to make this test and how to proceed if the results are not according to expectations.

Fig. 7.3 shows a typical frequency-changer circuit using a triode hexode. This is a valve having two assemblies on a common cathode—a small triode and a hexode which is a valve similar to an r.f. pentode but having a modulator grid located between the screens.

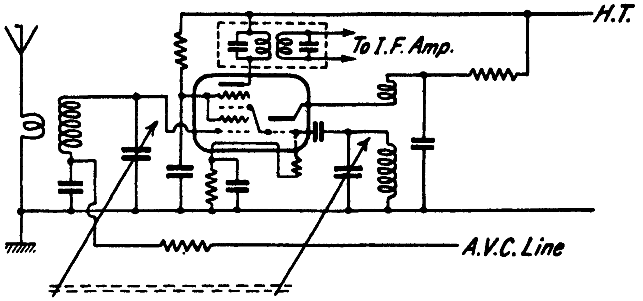

Fig. 7.3. Triode-hexode Frequency-Changer Circuit.

This modulator grid is connected, usually inside the valve itself, to the oscillator grid so that its potential varies at the oscillator frequency. The signal is applied to the control grid (nearest the cathode) and this causes the electron current to vary at signal frequency. The anode thus collects current which is modulated by both signals, giving a complex current which contains both the original radio frequencies together with a component at a frequency equal to the difference between the two. The strength of this

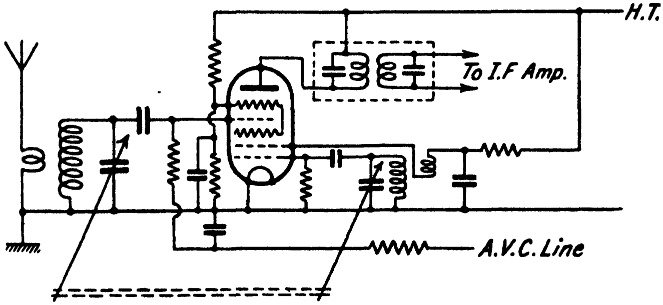

Fig. 7.4. Frequency changer using Heptode Valve.

depends upon the value of the r.f. signal applied to the control grid but is independent of the strength of the oscillator signal provided that this is more than a certain amount (specified by the makers of the valve). Hence the i.f. output in the anode circuit is of the right frequency and has a strength depending on the incoming signal. This i.f. component is selected by the i.f. transformer which has a negligible impedance to the r.f. components and thus by-passes them to earth.

Fig. 7.4 shows an heptode frequency changer. This has five grids, the first two of which are used as the grid and anode of a triode and serve to sustain the oscillation. The signal is injected on G_4, the third and fifth grids being screens. Because of the five grids the valve is sometimes called a pentagrid. In this case, therefore, the cathode stream is modulated by the oscillator first and subsequently modulated by the signal. The final result is the same though there are points in favour of both systems. In some circuits a suppressor grid is added. This is located between G_5 and the anode and is connected to cathode or earth. The valve is then known as an octode. Its action is similar.

There are other types of mixing system but one or other of the above types is usually found and since our purpose is to deal with basic principles rather than to go into voluminous detail it is felt that the reader will be able to cope with any special systems which he meets by simple modification of the fundamental technique.

Automatic Volume Control. The popularity of the superheterodyne has brought in its train the almost universal use of automatic volume control. This is the arrangement whereby the amplification, prior to the detector, is controlled by the strength of the signal at the detector, so that a strong signal automatically restricts the amplification and thereby limits itself, whereas on a weak signal the set is allowed to develop its full gain.

As a general rule, diode detectors are used for this type of circuit, two diodes being provided as indicated in Fig. 7.5. The first diode provides the signal-frequency rectification, a series connection of the diode being used for this purpose. The audio-frequency voltages are developed across the resistance R_1 and transferred through an isolating condenser on to the a.f. portion of the receiver.

The top of the tuned circuit, however, is also connected through a small condenser, usually of about ·0001 μF, on to the second diode, the load resistance of which is connected to the negative line. The voltage developed across this resistance R_2 is fed off through de-coupling circuits to the grids of the frequency changer and i.f. valves. The de-coupling circuits have a long time constant so that they ignore the signal-frequency variations and only respond to slow changes in average signal strength. Both frequency changer and i.f. valves have vari-mu characteristics, so that the amplification is progressively cut down as the bias increases. The a.v.c. diode is negative to the cathode by the volt drop on the cathode resistor. This gives a *delay*, the a.v.c. being inoperative until a certain strength of signal is attained.

Possible faults in the signal diode have already been dealt with in Chapter VI. Difficulty may conceivably arise in the a.v.c. portion of the circuit due to insufficient de-coupling, in which case the resistance or condenser, or both, must be increased. This process cannot be carried too far, however, or there is a noticeable time delay in the operation of the control which is unpleasant.

As a general rule it is preferable to connect the various de-coupling circuits in cascade as shown in Fig. 7.5, so that the earlier valves in the chain obtain more de-coupling than the later ones.

The possibility of automatic volume control on a receiver must always be borne in mind. For example, in making tests on the high-frequency performance it is desirable to throw the automatic volume control out of action. Otherwise, the self-regulating action may be coming into play and invalidating any tests or measurements.

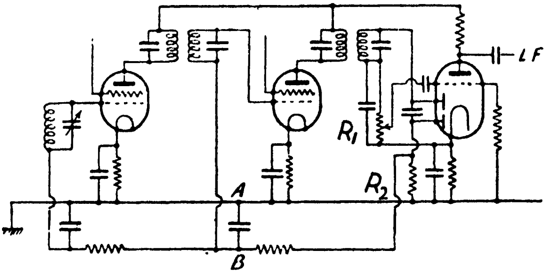

Fig. 7.5. Illustrating Application of A.V.C. to Superhet Receiver.

The a.v.c. can easily be rendered inoperative by short-circuiting the first de-coupling condenser of the chain, i.e. the points *AB* in Fig. 7.5. This prevents any bias voltage being transferred back.

The method of introducing the bias on to the appropriate grid varies in different receivers. Two alternative forms are shown in Figs. 7.3 and 7.4.

In some receivers the a.v.c. diode is fed from the anode of the r.f. valve since this usually develops more voltage than the secondary.

Alignment of Superhet Receiver. Let us now consider the technique of checking through a superhet either to locate a fault or to see that all the circuits are correctly adjusted. The first requirement is to develop a reference voltage at the detector.

This may be done by connecting a valve voltmeter across the secondary of the i.f. transformer feeding the detector. Still better, the earthy end of the diode load may be disconnected and a micro-ammeter inserted. Since the diode load will be of the order of 0·5 to 1·0 megohm, a voltage of 10 volts will only pass 5 to 10 micro-amps. Measurement of such a small current may be beyond the resources of the service engineer, but the method is useful in the laboratory because it does not disturb the circuit appreciably whereas the stray capacitance of a valve voltmeter across the circuit may have undesirable effects.

Another method is to measure the output voltage across the loud speaker, or to replace the speaker with an output meter. It is not difficult to calculate the voltage necessary on the grid to develop a given power, while if an a.f. oscillator is available a definite measurement can be made. It is desirable to choose a level well below full output to avoid difficulty with the a.v.c., although in case of doubt the a.v.c. can be rendered inoperative as explained in the last section.

As an example let us assume that the output stage is a high slope pentode fed direct from the diode (see Fig. 7.6) and that it requires 3 volts r.m.s. to develop 2 watts. Then 1 volt r.m.s. will develop 2,000/9 = 222 milliwatts. With 30 per cent modulation the carrier voltage required to deliver 1 volt r.m.s. a.f. signal will be 1·4/0.3 = 4·66 volts. (The 1·4 is because we must convert the r.m.s. voltage to its peak value. This peak, divided by the carrier voltage, gives the modulation depth = 0·3.) To allow for detector loss we can assume 5 volts, corresponding to just over 90 per cent efficiency. On this basis we can assume that, provided our signal generator is modulated to a depth of 30 per cent reasonably accurately, an output of 222 milliwatts corresponds to 5 volts of i.f. signal at the detector and this is our starting point.

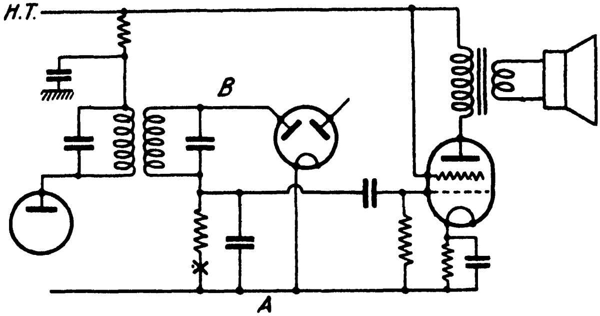

Fig. 7.6. The Detector may be arranged to feed direct to a High-slope Output Stage.

We can now proceed to check the gain of the i.f. stage, which we do by connecting the signal generator to the grid of the i.f. valve and adjusting the output (and the tune) until we obtain the standard output. If we find this requires 25 millivolts the gain of the stage would be 200. It is not usually necessary to disconnect the i.f. transformer feeding the grid of the i.f. valve because the output of the generator will be at a low impedance and the transformer secondary will have negligible effect unless there is a short circuit. If the results are not up to expectations, however, this transformer should be disconnected and a fresh check made.

Checking the I.F. Tuning. If the stage gain is very low some definite fault probably exists. The screen and bias voltages should be checked and the circuit generally examined as already laid down. If the gain is merely poor the circuits may be mistuned and a retune should be tried. Truly accurate ganging requires a critical adjustment of the tune to obtain the double-hump resonance curve which gives the flat top at which the designer aims. As we have seen, the most satisfactory procedure is to use a cathode ray oscillograph, but where this is not available or practicable, the following method may be used. A large condenser of, say, ·001 μF, is connected across the first circuit which throws it completely out of resonance. The input of the signal generator is then increased so that current is forced through the transformer until an adequate voltage is developed across the secondary. This will probably require an increase of 100 times in the output from the generator because we have lost all the gain due to primary resonance. The secondary may then be tuned to the maximum, which may be done quite definitely, since such an arrangement will only have one tuning point.

The swamp condenser should then be transferred to the secondary and the primary tuned. This will destroy the resonance of the secondary, and the primary will only have one tune. Both circuits will now be tuned to the same frequency and it will then be found, on removing the condenser across the secondary, that if the frequency of the signal generator is varied the transformer will show the required double-hump characteristic.

By this means the circuit may be lined up and the gain should be of the order required. It is important to carry out any tuning at the correct intermediate frequency specified by the makers because the tracking of the oscillator section (described later) will have been calculated for this frequency and the use of another frequency may make perfect alignment impossible.

Frequency Changer. The next feature is the frequency changer, which must be checked to ensure that it is operating in its correct condition. The first check is to use this valve as an i.f. amplifier by applying intermediate frequency signals to the grid and noting the gain either of the valve by itself or else the whole circuit. Usually only one i.f. stage is used, and if the gain of this has already been determined, then by measuring the overall gain of both frequency changer and i.f. valve one automatically obtains a check on the performance of the frequency changer and the whole amplifier. It is to be noted, however, that the i.f. gain of the frequency changer is usually at least twice that from the valve acting under its normal conditions, and it may be found that the whole circuit is unstable. In such circumstances the only remedy is to measure the gain of the frequency changer alone.

To do this it is necessary to connect a valve voltmeter across the secondary of the i.f. transformer in the anode circuit of the frequency changer. The connection to the grid of the i.f. valve should, of course, be removed. The capacitance of the valve voltmeter across the circuit will not be equal to that of the i.f. valve which it replaces, so that we must re-tune the secondary in order to obtain maximum signals. When the valve voltmeter is removed the capacitance must be readjusted to the normal value once again. If necessary the circuits may be tuned by using the technique already proposed for the i.f. stage.

Checking Conversion Gain. Having checked the gain of the frequency changer as an i.f. amplifier, which should be of the same order as that of the i.f. valve itself, the conversion gain may then be checked. For this purpose the circuit is left exactly as before, but it is now supplied with *signal frequency* from the generator. A frequency about the middle of the tuning scale is usually chosen, and the tuning control of the receiver is then rotated until the oscillator frequency reaches the required value when it will mix with the incoming signal and be converted to intermediate frequency. The tuning control is, therefore, rotated until the maximum reading is obtained.

It may be remarked here that there are two possible oscillator frequencies, one above and the other below the signal frequency. Either of these will give a difference frequency of the required i.f. Almost invariably the oscillator works at a higher frequency than the signal (for convenience in tracking) and this frequency should be used. In any case the control of oscillator frequency will be obtained by varying the main tuning dial of the set and the reading on this should correspond to the signal frequency chosen for the test.

Generally speaking, the conversion gain is about half that of the valve acting as an i.f. amplifier. Under certain conditions it can be rather more than this, but if it is seriously less, then the circuit should be investigated to find out why. Using an electron-coupled frequency changer, the reason for a low conversion gain is usually to be found to lie in an insufficient oscillator voltage and this is perhaps one of the next things to check.

Oscillator Voltage. The oscillation of the frequency-changer stage may be checked by touching the grid of the oscillator. This should produce a "plop" in the loud speaker. A better test is to measure the anode current. With most circuits the h.t. voltage is applied to the oscillator through a de-coupling resistance (cf. Fig. 7.3). Connect a voltmeter across this and touch the grid with the finger. If the reading changes, denoting a change in anode current, the circuit is oscillating, because the anode current of the valve is less in the oscillating condition. If no oscillation is present the oscillator circuit must be examined in detail.

Sometimes it is necessary to check the value of oscillating voltage. This may be examined by connecting a valve voltmeter across the appropriate electrodes in the frequency-changer valve. If a triode hexode is being used, the voltmeter should be connected across the modulator grid (usually tied to the oscillator grid). With a pentagrid, it should be connected across the first grid, while if a separate oscillator is being used, it should be connected across the tuned circuit of the oscillator. The tuning control should then be rotated over the scale on both wave-bands, and the oscillation should be equal to or greater than the specified minimum limit over the whole scale. If it is found to be low, the voltages on the various electrodes should be checked. If these are in order, then the design of the oscillator coil is at fault and suitable modification should be made.

Failing a valve voltmeter, the grid leak on the oscillator may be disconnected at the earthy end and a milliammeter inserted. The product of the current and the leak resistance will give the peak oscillator voltage. Thus with a 50,000 ohm leak a current of 0·2 mA would indicate 10 volts peak and 7.1 volts r.m.s.

If trouble still remains it may be that the frequency of the oscillator is incorrect. The wave-change should be examined to make sure that the oscillator is operating on the correct wave-band. If possible the actual frequency of the oscillation should be checked by using the wave-meter as an absorption instrument.

It is sometimes suggested that the oscillator should not be in operation when checking the frequency changer as an i.f. amplifier. This is not correct because the oscillation causes the oscillator grid to take up a negative potential and the performance of the valve is based on the assumption that the triode grid (and any other grids connected to it) will be operating at this potential.

The negative grid potential is characteristic of any triode oscillator having a grid condenser feed. The peaks of the oscillating voltage draw grid current which charges the condenser negatively. This charge leaks away through the leak and the oscillation automatically adjusts itself to an equilibrium condition at which the grid current pulse just makes good the leakage every cycle.

Signal-Frequency Circuits. The next point to be checked is that of the signal-frequency circuits. As already explained the practice is nearly always to use at least two signal-frequency circuits arranged either as a band-pass tuner or as an r.f. stage. In checking this, a valve voltmeter should be connected across the signal grid of the frequency-changer valve, and the valve itself should be removed. This removes the additional capacity due to the frequency-changer valve and substitutes for it capacity of the valve voltmeter. As a general rule, these will be found to be sufficiently similar for practical purposes. The ganging of two or more signal-frequency circuits must then be carried out in accordance with the principles laid down in Chapter V for ganging of straight sets, and the circuits must be so adjusted that they cover the full wave-length range required on both wave-bands.

It is convenient, when the receiver is first being designed, to plot a chart showing the relation between dial setting on the tuning condenser and signal frequency. This will be found helpful in adjusting the tracking of the oscillator later on. This operation is, of course, unnecessary in routine testing, since the constants of the circuit will by that time have settled.

Tracking. We now come to the important question of tracking of the oscillator circuit with the signal circuit. It is necessary that the oscillator frequency shall differ from the signal frequency by a constant difference equal to the intermediate frequency. It is found that the most convenient arrangement (in fact, in some circuits the only possible arrangement) is obtained when the oscillator frequency is higher than the signal frequency by the specified figure.

Now, obviously, the ordinary condenser by itself will not fulfil these requirements, even with a modified value of inductance. If the ordinary frequency range to be covered on the medium waves is 550–1500 kc/s, corresponding to a capacitance range of 7.45, the oscillator frequency must vary over some higher range of frequency. If we assume the intermediate frequency to be 450 kc/s the oscillator must range from 1000–1950 kc/s which corresponds to a capacitance range of only 3·8.

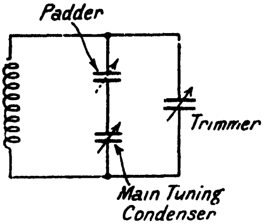

Fig. 7.7. Tracking Circuit for Superhet Oscillator.

There are various ways in which the restricted capacitance range can be obtained. One is to use a special oscillator section having a smaller capacitance than those used for the tuning. This is not enough by itself, for although the frequency might be correct at the beginning and end of the scale, it does not necessarily follow that the tuning capacitance would be correct in the middle, so that oscillator plates have to be specially shaped. This practice is occasionally adopted, particularly with receivers which only operate over one wave-band, but it is clear that any such special shaping can only apply for one wave-band, and if, as usually obtains, two or more wave-bands have to be covered, some additional arrangements will be necessary.

Partly for this reason the alternative method, that of padding and trimming, is usually adopted. We can restrict the capacitance range by the inclusion of a fixed condenser in series with the oscillator tuning condenser. This reduces the effective maximum capacitance, and such an arrangement will, with a suitable inductance, enable us to cover the frequency range required. We can also obtain a similar coverage by placing a large parallel condenser across the condenser, since this again will restrict the capacitance range and, in conjunction with a different value of inductance, will again give us the necessary coverage.

Neither of these two, however, will necessarily be correct in the middle, and it will be found that one method will give too low a frequency in the middle of the scale, and the other will give too high a frequency. Clearly, therefore, the solution is to adopt both methods at once and to choose a third point in the middle of the scale at which the ganging may be made to be correct. We then have three variables, namely, the oscillator inductance, the parallel trimming condenser, and the series padding condenser, and three frequencies which are to be "spot on." It is possible to fulfil these completely with a result that we obtain a condition in which the tracking is exactly right at the ends and middle of the scale, and varies slightly between these points. With skilful design the variation is only small and the tracking is quite satisfactory for practical purposes. Fig. 7.7 shows the type of circuit used.

Adjustment of Tracking. So much for the method used. The designer will have worked out the values of padder and trimmer required, but it still remains to adjust these values in actual practice. The trimmer capacitance, in particular, is usually fairly small on the medium waves, and since it includes the stray capacitance in the circuit it must obviously be variable so that minor differences in assembly can be allowed for.

In adjusting the trimming, the principle to remember is that alterations to the padding condenser mainly affect the maximum, while the minimum is controlled largely by the trimmer. Some small interaction between the two is obviously unavoidable, but this is usually negligible except where the padder is small or the trimmer large or both. Such a combination occurs on the long waves with 450 k.c. intermediates.

The procedure, therefore, is to set the main tuning dial to a point at the bottom of the wave-length scale. The signal generator is connected to the signal grid of the mixer and adjusted to the frequency indicated on the dial. This avoids any difficulties due to the r.f. circuits being out of gang. The trimming condenser in parallel with the oscillator condenser is now adjusted until the maximum output is obtained on the receiver.

The set is now tuned to a second ganging point at the top of the medium wave scale and the signal generator adjusted to this frequency. If the set has a variable padding condenser this should now be adjusted again to give maximum output. If the padding condenser is fixed, the set should automatically be giving maximum output and the tuning condenser should be rotated slightly on either side of the tuning point to make sure that this is so. If it is not so, then either the oscillator inductance or the padding condenser are incorrect and should be modified accordingly.

Finally, a check is made on the third ganging point in the middle of the scale and this should at once give the optimum output. If it does not do so, a small adjustment of the trimmer condenser may be resorted to, and it is sometimes found necessary to permit both the middle and bottom points of the scale to be slightly out, in order to obtain a good compromise.

When this adjustment is completed the signal generator may be transferred to the aerial terminal when the set should give its proper output everywhere. If it does not the ganging of the aerial (and r.f. circuit if any) is out and should be readjusted. *The oscillator should not be altered.*

In the laboratory the test points are specified by the designer, these being the points at which the tracking was calculated to be correct. The service engineer may not have knowledge of these points and must perforce choose random points. He should not, therefore, expect perfect tracking, but it will be possible to get very close with reasonable care.

Alignment of I.F. Stages. The i.f. stages should always be tuned to the value specified by the makers as otherwise optimum performance is not to be expected. If the correct i.f. is not known, choose an arbitrary value and line up the i.f.'s and adjust the tracking in the middle of the scale. If the i.f. chosen is *higher* than the designer's value, it will be found that the higher wave-length settings of the signal circuit requires *increased* capacitance for correct tracking, while if the i.f. chosen is too low a decreased capacitance will be required at the higher wavelengths. A little trial and error will then enable the correct i.f. to be arrived at.

Checking Oscillator Frequency. In the design stages it is convenient to check the frequency of the oscillator circuit. To do this the signal frequency circuits are set to a number of points over the scale. The frequency of these points is already known from the calibration which has been made. The oscillator frequency at these points is then checked by an absorption wavemeter. This is a simple coil-condenser combination calibrated in frequency or wave-length. The coil is brought near the oscillating coil, and when the circuit is brought into tune, the amplitude will suddenly change. This change may conveniently be noted by connecting a milliammeter in the anode circuit of the oscillator valve or oscillator section of the frequency changer, when a small dip or flick in the current will be noted when the wavemeter comes into tune. The wavemeter should be placed just near enough to observe this flick. It should not be placed any closer than necessary or it may affect the frequency of the oscillator circuit.

In this way the oscillator frequency can be checked at each of the various points, and this can then be compared with the theoretical oscillator requirements.

I.F. Instability. Instability in the i.f. stages may be experienced, and if so, its cause will be one of the various sources of instability in r.f. amplifiers already discussed. The principal difference is that due to the lower frequency in use, the constants of the circuit will need to be slightly different. For example, the by-passing either of anode de-coupling or of self-bias arrangements needs to be more effective so that slightly larger values of by-pass condensers have to be employed. Earthing is equally important, for instability can arise due to bad earth or the use of the chassis an as earth connection, although not to the same extent as with a straight r.f. amplifier, because the lower frequency in this instance is an advantage rather than the reverse. On the other hand, due to the lower frequency, the tuning circuits can be made more efficient and the gain obtained from the i.f. valves is usually in the neighbourhood of 200 or even more, which means that stray couplings are of considerable importance, and every precaution must, therefore, be taken.

The symptoms of self-oscillation in the intermediate frequency stages are an abnormal number of whistles which change pitch as the tuning control is rotated.

If instability of this nature is experienced the offending valve must be located. A good plan is to measure the anode current of each of the i.f. valves in turn and then to tap the grid of the said valve with the finger. If the circuit is oscillating there will be a large change of anode current, due to the fact that the valve will cease to oscillate when the finger is placed on the grid. Remembering that the frequency changer must be included in the i.f. amplifier for such tests.

The anode current may be measured by breaking the circuit and inserting a milliammeter or by measuring the voltage drop across the de-coupling resistance, if such is provided.

Birdies. Apart from whistles caused by instability of the i.f. stages, trouble may sometimes be experienced due to annoying whistles which appear as a background to the various stations which are tuned in. These whistles, often known as "birdies," may, on a poor receiver, be almost continuously present and be particularly obnoxious on one or two stations. Their avoidance is largely a matter of correct design, but the performance of a set can sometimes be improved by simple modifications.

The general cause of the trouble is insufficient signal-frequency selectivity resulting in appreciable strength being received from local stations at points considerably off tune. Therefore, anything which tends to improve the signal-frequency selectivity will reduce the whistles. For this reason it is the customary practice to use band-pass tuning for the aerial circuit, or else to use a high-frequency stage. In such circumstances the precautions mentioned under the heading of "remote channel selectivity" in Chapter V apply quite forcibly. Particular care must also be taken to ensure that the secondary circuit of the band-pass (or the r.f. transformer) is adequately shielded and that the leads from the tuned circuit to the valve are also shielded. Otherwise, direct pick-up on these leads will re-introduce the residual signal from the local station which should have been filtered out by going through the whole chain.

Where a receiver is operating very close to a local station it is also helpful to include rejector circuits tuned to the frequency of the local station.

CHAPTER VIII

MAINS APPARATUS

IN addition to the various forms of test already described, certain additional tests have to be applied where apparatus is designed for operation from power mains. Such apparatus may be designed to operate as a whole from the electric light supply, or it may be designed to supply the voltages to an existing receiver, in replacement of the customary batteries. The methods of testing are similar in the two cases, and we shall, therefore, consider in general the complete mains receiver, the mains unit or power pack, as it is sometimes called, being a particular case of general proposition.

Electric light mains are of two kinds known as d.c. and a.c. respectively. In the d.c. variety, current flows continuously in one direction, whereas in the case of a.c., the current flows first in one direction and then in the other, alternating in this manner a large number of times per second. The total number of alternations or cycles per second is termed the frequency of supply, and in this country varies between 25 and 100 cycles per second according to the locality. In America the frequency is universally 60 cycles per second, while the supply in this country is being standardised at a frequency of 50.

D.C. Supply. We will consider the case of the direct current (d.c.) supply first. It is clear that we can utilise such a supply to provide the high voltages necessary for the anode circuit of the receiver in replacement of the customary h.t. battery. It is, of course, necessary to know which of the mains is the positive pole, and this may easily be determined by the aid of a pole finder. The use of this device, however, is seldom necessary, because the apparatus will only work when the mains are connected the correct way round; if they are wrongly connected no results will be obtained. It is a simple matter of trial and error, reversing the plug in its socket if the set does not work the first time.

If it is desired for any reason to ascertain which is the + pole, a voltmeter may be connected across the mains, making sure, of course, that the range is such that the full voltage comes within the scale. The voltmeter, of course, will only read correctly if the + terminal is connected to the + pole. Otherwise it will read in the wrong direction.

Generally speaking, the supply of current from an electric light main is such that it cannot be used to replace the h.t. battery without certain precautions. A direct current usually comprises a steady voltage together with a small alternating component, known as ripple. This ripple is produced by the generators at the power station, and usually has quite a high frequency, in the neighbourhood of 200 to 500 cycles per second. Before the supply can be used on a radio receiver, it is necessary to smooth out the ripple by the aid of a filter circuit such as that shown in Fig. 8.1. It should particularly be observed that in the d.c. case no condenser is required on the supply side of the filter. The generators at the power station supply unlimited power and no provision need be made to store up the energy. It is thus not necessary to have a reservoir condenser as in the case of a.c.

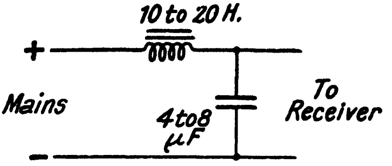

Fig. 8.1. Simple D.C. Filter.

Voltage Tappings. The full voltage is employed for the output stage and usually for the other stages as well. The detector, however, may require less than this, while certain parts of the circuit, such as the screens of the r.f. valves, may only need about 80 volts.

For such purposes, therefore, it is necessary to sub-divide the voltage, which may be done with a potential divider of the form shown in Fig. 8.2, which provides tappings at 120 and 80 volts in addition to the full output.

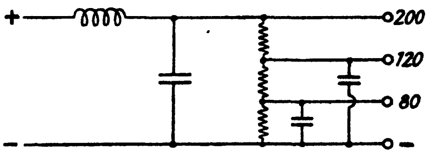

Fig. 8.2. Simple Potentiometer for Sub-division of Voltage.

Motor-boating. A simple form of potentiometer, however, is liable to introduce serious back-coupling in the receiver, due to the common impedance in the h.t. circuit as explained in Chapter IV. This produces low-frequency oscillation which gives a continuous "pop, pop, pop," sounding somewhat like the exhaust of a motor-boat. If this is experienced with a receiver operating from a mains unit of the type described, arrangements must be made to incorporate filters in each h.t. lead, so that the audio-frequency currents can be prevented from flowing through the internal resistance of the mains unit. Alternatively, the arrangement of the mains unit may be slightly altered, as shown in Fig. 8.3, so that a common resistance in the h.t. circuit is avoided.

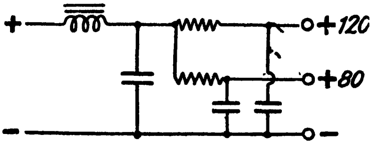

Fig. 8.3. Re-arrangement of Fig. 8.2 to Prevent Back-coupling.

Regulation. Assuming that the instrument is developing some other form of trouble, the first step is to measure the voltage at the various points. The voltmeter must be of a high-resistance type (at least 1,000 ohms per volt as already described), so that the current taken by the meter is negligible. The reason for this is that owing to the internal resistance of the mains unit, the voltage on the output terminals depends considerably upon the current that is being taken..

Mains units, as a class, have a bad regulation, rendering them essentially different from batteries, which maintain the voltage fairly constant irrespective of the load. It should always be seen that the unit is working under its actual operating conditions, i.e. that it is supplying the current which it is called upon to do in use. Check the voltage from the mains through the circuit up to the h.t. points of the receiver. It is easy to find if an undue voltage is being lost at any point, and so to ensure that the receiver is obtaining its proper supply of h.t. voltage.

Three-wire System Dangers. There is one point which must be emphasised strongly in connection with direct current mains. Most of the supply in this country is on what is known as the "three-wire system." Voltage is generated at 400 to 500 volts, a centre-tapped arrangement being provided on the generators. The centre point is connected to earth, so that we have two supplies of 200 or 250 volts, and the greatest difference of potential above or below earth is only 250 volts. This is done for reasons of safety, but the point is that on one side of the supply the earth is on the negative pole, while on the other side of the supply the earthed pole is the positive.

Now in a radio receiver we nearly always connect the H.T. - point to earth. The result is that if we endeavour to obtain h.t. voltage from power mains in which a positive pole is earthed, then if we connect this to a radio receiver, we shall obtain a direct short circuit which will blow the fuse. To obviate this, one must **never connect** a device operating from the d.c. mains **directly to earth.** A condenser should be connected between the earth terminal on the receiver and the earth itself, and this will avoid the difficulties mentioned. This condenser must, of course, be sufficiently strong to withstand the d.c. voltage applied across it, and should have been tested at a voltage at least twice that of the d.c. supply. A value of 0·1 to 1 μF is used according to circumstances.

It is also essential to have a good condenser in this position, preferably of a non-inductive type. Cases have occurred where a set was made unstable at certain points of the scale by a bad earth condenser.

D.C. Receivers. Apart from the use of an h.t. power pack, it is possible to design a receiver to operate entirely from the d.c. supply. For this purpose, indirectly-heated valves are used similar to the a.c. types discussed later, except that the heaters take a smaller current at a larger voltage. Some valves take 0·2 amps at voltages up to 40, but the tendency is to standardise on the 0·3 amp range at voltages which are multiples of 6·3. (See later under Universal Receivers.) These heaters are all connected in series, the current being supplied by the full mains voltage through a suitable resistance, which is provided with tappings to suit voltages ranging from 200 to 250.

The high tension supply is obtained direct from the mains through a smoothing choke and condenser in the usual way, a typical circuit for a simple receiver being shown in Fig. 8.4. It will be noted that the r.f. and output valves are supplied with the full h.t., while the detector valve obtains a lower h.t. through a series dropping resistance which serves not only to reduce the voltage on the anode of the valve but provides de-coupling so that feed-back is avoided as already explained. The screen feed to the r.f. valve is obtained by a potential divider across full h.t., this being a more satisfactory arrangement because the screen current is inclined to be variable, and with a simple series resistance feed the effective voltage on the screen may vary widely, whereas with a potentiometer arrangement as shown it is held within reasonable limits.

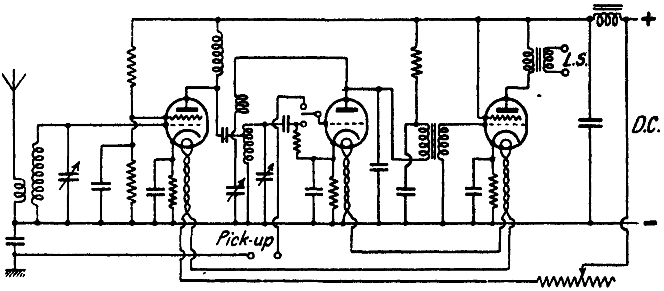

Fig. 8.4. Typical D.C. Receiver.

The wiring of the heaters should be noted. It will be seen that the detector valve heater is at chassis potential. Although the valves are indirectly heated, hum may be introduced through the capacitance between heater and cathode. It is customary, therefore, to arrange that the valves in the chain which are most sensitive to hum are connected at the low potential end, followed in succession by the valves of less sensitivity.

The self bias arrangements in this circuit are similar to those adopted in a.c. sets as is discussed later in the chapter.

Ordinary Tests. Apart from these considerations d.c. receivers are straightforward and call for no special treatment. The customary tests for tuning, r.f. and a.f. amplification, and so on, must be applied in the manner already described in the previous chapters, the only difficulty being that no valve can be removed from its socket without making the whole circuit dead. Generally speaking, the best method of procedure is to check through the voltages, starting from the mains and working downwards to see that the voltages that are applied to each valve are of the correct order. If any difficulty remains, it is usually due to some simple fault not connected with the mains drive, but due to some inherent defect in one of the components.

It should be emphasised that any testing carried out with a voltmeter on a mains set should preferably be done with a couple of test prods, consisting of long ebonite rods having spikes at the end. This avoids the risk of shock, in case one accidentally catches hold of live parts. The risk of shock with d.c. apparatus is not as great as with a.c. apparatus, but nevertheless no unnecessary risks should be taken.

Any tests other than the actual measurement of the voltages in the circuit should be made with receiver switched off, and the plug removed from its socket, so that the receiver is completely dead. There is then no risk of shock or of stray voltages damaging the instrument.

D.C. Hum. The most difficult problem to overcome in connection with d.c. apparatus is usually the hum produced in the receiver by the ripple already referred to. This is of a fairly high frequency, and can often be unpleasantly loud. Hum directly fed into the circuit can be eliminated by the use of filtering circuits of the type described. As a rule the filter circuits are already incorporated in the apparatus and should be adequate. If there is any doubt on the point, however, an additional filter circuit may be introduced in the h.t. lead, or the effect may be tried of adding an additional capacitance of, say, 8 μF in parallel with the smoothing condenser in the set.

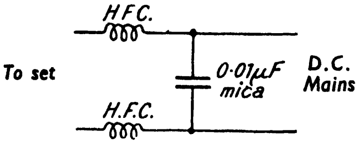

Fig. 8.5. H.F. Chokes are Sometimes Necessary in D.C. Mains.

In some cases a high-frequency disturbance may be experienced due to radio-frequency currents, modulated at hum frequency, which are introduced into the set via the mains leads. Such interference may be removed by connecting a filter in the mains lead as shown in Fig. 8.5. These chokes must have an inductance of 5,000 to 10,000 microhenries, should be wound in sections or wave-wound to minimise self-capacitance, and the wire must be of sufficiently heavy gauge to carry the full current without serious voltage drop or overheating.

Induction. Direct induction is another source of hum. Certain parts of the circuit may be associated with the mains leads and thereby have small ripple voltages induced therein. The detector circuit is most vulnerable in this respect and may have to be very carefully shielded. Since the d.c. ripple is of relatively high frequency the induction effect is often considerable.

All mains and heater leads should be twisted and kept away from the detector circuit. It is often useful to make the detector valve at earth potential, where practicable, as has been done in Fig. 8.4.

Long loud speaker leads are liable to pick up induction hum whether the set is operated from the mains or not. Twisted or lead-covered wire should be used in such cases. The location of hum is discussed further on page 152.

A.C. Supply. The greater percentage of electrical supply in this country is alternating (a.c.), and this is in many ways more convenient. In the first place it is distinctly safer in operation, for the receiver can be completely isolated from the mains, and therefore it is possible to ensure absolute safety from shock in use. The disadvantage of a.c. lies in the fact that it is necessary to rectify the current so that it flows in one direction only, and then to smooth out the resulting current so that it is substantially steady and free from variation.

A brief description of the method of rectification and smoothing will be desirable. We obtain voltage from the supply through a transformer. This is an instrument which contains two windings on an iron core. The mains supply is connected across one winding and an alternating voltage is developed across the second winding, bearing a relation to the mains voltage depending upon the relative number of turns. We are thus able to step-up or step-down the voltage to any required extent, and this flexibility is one of the greatest advantages of alternating current operation.

Single-Wave Rectification. Having obtained our output voltage, we apply this to a rectifier which is generally one of three forms. The simplest is shown in Fig. 8.6, and is known as a Single-Wave Rectifier. It is either in the form of a valve, or a metal-chemical combination, which has the property of passing the current only in one direction. When the voltage is in the right direction, the current is passed into the condenser *C* and charges it up. In the reverse direction no current flows, and the condenser remains charged. The next time the voltage is in its original direction, current will flow as soon as the voltage rises above the voltage to which the condenser has charged, and a further charge will flow to the condenser, resulting in a rise in voltage. This process will continue until the condenser has built up to a voltage equal to the maximum value of the alternating voltage.

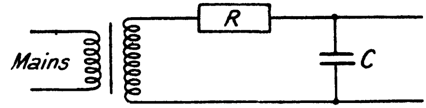

Fig. 8.6. Single-Wave Rectifying Circuit.

It should be pointed out here that this value is approximately 1·4 times the rated value of the alternating voltage. Alternating voltages or currents fluctuate in a regular and rhythmic manner, the variation of voltage with time usually being of the form shown in Fig. 8.7. If the voltage is varying from moment to moment in this manner, we clearly have difficulty in deciding what value the voltage shall be said to have, and, as explained in Chapter II, it has been

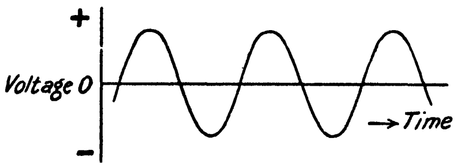

Fig. 8.7. Form of Alternating Voltage.

decided that if the heating effect of two currents, one a.c. and the other d.c., are the same the currents shall be considered equivalent. This involves the use of a somewhat complex unit known as the root-mean-square value, the derivation of which was explained on page 18.

With the ordinary sine wave encountered in general practice this value is approximately 0·71 times the maximum value, whence we obtain the relationship that the maximum value of the voltage or current is 1·41 times the r.m.s. or rated value.

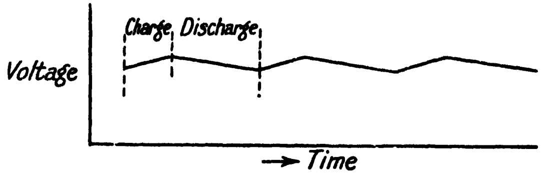

Fig. 8.8. Variation of Voltage on Reservoir Condenser.

High Voltage. This little explanation is necessary in order to understand some of the effects which will happen. For example, if we have a transformer giving 100 volts on the secondary in a circuit such as that shown in Fig. 8.6, then if there is no load connected across the condenser we should find that the voltage across the condenser would rise to 140, and if we measured this with a meter taking no appreciable current, we should obtain a reading of 141. This tendency of the voltage to rise to a much higher value than normal when there is no load across the condenser is one of the most important factors to be borne in mind when dealing with alternating current apparatus, for it is no pleasant experience to obtain a nasty shock of some 400 volts or so from apparatus supposed to be developing only a little over 250.

Normally, however, we connect some form of load across the condenser and this draws off a certain amount of charge during the period when the rectifier is not passing any current. What actually happens in practice, therefore, is that the condenser is continually charging and discharging slightly, rather in the manner shown in Fig. 8.8, which will be seen to be equivalent to a steady voltage with a small alternating voltage superimposed.

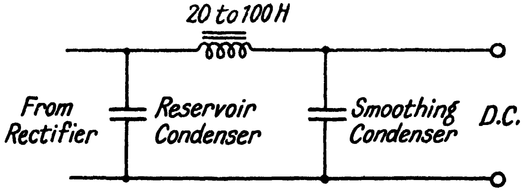

Fig. 8.9. A.C. Filter Circuit.

This is unsuitable, as it stands, for radio work, just as d.c. supply is unsuitable, and we must connect a choke and condenser filter across the apparatus, so that our final circuit is of the form shown in Fig. 8.9. As in the previous instance the choke must be of such a character as to carry the necessary direct current without saturation, but the inductance must be considerably higher than in the corresponding d.c. case, because the fluctuations are at the same time more severe, and lower in frequency than with the d.c., and are thus not so easily filtered out.

Double-Wave Rectification. The second form of rectification is known as the Double Wave type, and is illustrated in Fig. 8.10. Here the operation is the same except that two rectifiers are employed and the transformer is made with a double winding on the secondary, the two being connected together in the centre. Thus when the voltage is such as to give a positive potential on the top rectifier, current flows into the condenser in the ordinary manner.

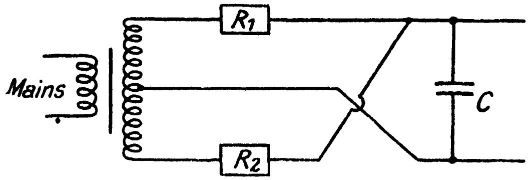

Fig. 8.10. Double-Wave Rectifying Circuit.

The next half cycle, however, the current is negative on the top rectifier, but is now positive on the bottom rectifier Therefore currents flow into the condenser again by a different path, but in the same direction. Thus we utilise each half of the alternating voltage which gives us smoother working, and also a greater output voltage on the condenser.

This latter point will be obvious, for if we are taking a given amount of current from the condenser, and we supply a pulse of current, every $\frac{1}{50}$ of a second we shall obtain a certain equilibrium voltage on the condenser at which the current supplied in pulses equals the steady current taken out. If we feed our current in pulses 100 times per second (i.e. twice as often) we are putting in more than we take out, and the voltage will rise in consequence till we obtain an equilibrium condition once again.

As a guide to the order of affairs as may be expected, the curve shown in Fig. 8.11 indicates the voltage output from a representative rectifier of the Single Wave and Double Wave type.

Regulation. Fig. 8.11 also illustrates a further reason for the inherently bad regulation of mains h.t. units. It has already been pointed out that, due to the inevitable resistance of the smoothing choke, the output voltage will be less than the full amount by an extent depending on the value of the current being taken.

The curves of Fig. 8.11 show that with an a.c. receiver there is a further source of loss, for the voltage on the input—i.e. the reservoir condenser—is itself dependent on the load, falling off as the current increases. The regulation due to this cause depends on the value of reservoir capacitance, but this cannot be increased too much or the current pulse supplied by the rectifier each half cycle becomes excessive. A value of 8 μF is the usual.

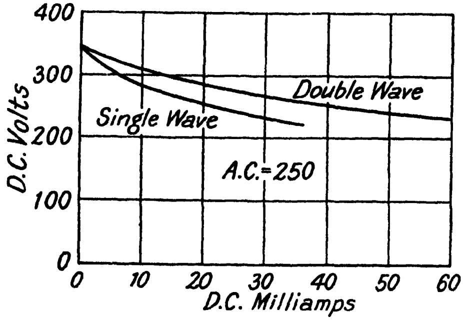

Fig. 8.11. Voltage on Reservoir Condenser with Typical Valve Rectifiers.

Bridge Rectification. There is a third form of circuit more commonly employed with metal or chemical rectifiers, which is known as the Bridge Arrangement. This is illustrated in Fig. 8.12, and it will be seen that four rectifier elements are used. When the top of the transformer winding is positive, the current flows through the path *AB* through the load, and then through the path *DC*. The next half cycle at the bottom end of the transformer winding is positive, the currents flow through the path *CB* through the load, and then through the path *DA*. It will be observed that the reservoir condenser is charged in the same direction each half cycle, so that we really have obtained a similar state of affairs to the Double-Wave rectification without having to employ a double voltage secondary with the centre tap, but at the expense of two further rectifying elements. The voltage on the reservoir condenser bears much the same relation to the voltage on the transformer secondary as that for Double-Wave rectification, in Fig. 8.11.

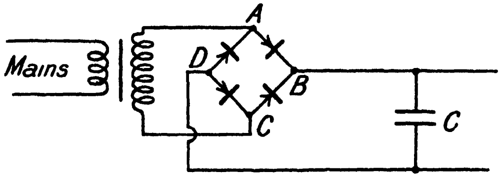

Fig. 8.12. Bridge-Rectifying Circuit.

Voltage Doubler Circuits. A further form of circuit becomes practicable with metal rectifiers. This is the voltage doubler circuit shown in Fig. 8.13.

When the point *A* is positive current flows through the path *ABC*, charging the condenser *BC*. The next half cycle current flows via *CDA*, charging condenser *CD*. These voltages are in such a direction as to add up, giving a double voltage across the load.

Thus an 80-volt secondary winding will give 120/180 volts d.c. according to the load with consequent economy on the transformer. The condensers, however, should be larger than usual because they are effectively in series. If they are not increased the regulation of the system is adversely affected and in general it is found that voltage doubler circuits have bad regulation.

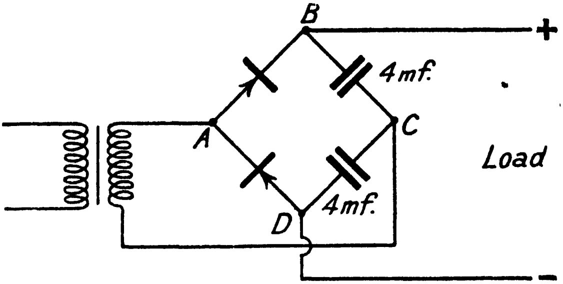

Fig. 8.13. Voltage Doubler Circuit.

Faults on A.C. Power Packs. Having dealt with the broad principles of rectification in this manner, we can discuss the faults which are likely to arise in this portion of a mains apparatus. Strictly speaking, the first operation, following out our usual sequence of events, is to measure the voltage on the secondary of the transformer. This of course requires an a.c. voltmeter, and in some cases this voltage is of a dangerous value, exceeding 250 volts, so that the greatest care is necessary in this connection. It may be taken for granted, however, that a faulty transformer is not the most common defect in this class of apparatus, and we may perhaps make a more convenient starting point by measuring the voltage across the reservoir condenser (which is d.c.). For this purpose a high-resistance voltmeter must be used, and it must, of course, be capable of reading the probable voltage well within its scale. If the normal output voltage of the eliminator is, say, 120 volts, then the reservoir condenser may read anything up to 250 volts.[1] The measurement should be made with the apparatus in a working condition, i.e. supplying a load, as otherwise misleading results may be obtained.

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[1] The voltage on the reservoir condenser will, in any case, exceed that on the output, to allow for the voltage drop on the subsequent smoothing circuits. If there is a fault on the circuit so that no current flows there will be a further rise in the voltage of approximately 40 per cent as already explained.

If the voltage is found to be of the correct order, then the portion of the equipment up to the reservoir condenser is satisfactory. If the voltage is higher than one would expect, this probably indicates a break somewhere later on in the circuit, so that the apparatus is not supplying its full load. This may be checked by continuing the voltage tests as described in a moment. If, on the other hand, the voltage is low, this shows an excessive load, or a defective transformer or rectifier. Check the transformer voltage. With a double wave circuit only half the transformer may be working, causing the circuit to become a single wave arrangement, which will deliver a lower voltage owing to its poorer regulation.

A defective rectifier may produce the same result for if one side of the rectifier is low in emission it will fail to pass enough current to charge the condenser appreciably during the half cycle when it is in action. With sets taking a heavy load any such defect is aggravated if the voltages on the two halves of the transformer secondary are not exactly equal and this is often found to be the cause of low voltage, bad regulation and excessive hum.

Discharging the Condensers. If the voltage is zero and the transformer is not defective, this suggests a short circuit across the output. The apparatus should be switched off, and the connections leading from the reservoir condenser to the remainder of the apparatus should be removed. Leave on those connections which come from the rectifier. Incidentally, as a precaution, the principal condensers in a power pack or mains-driven receiver should always be discharged, after the current has been switched off, before any alteration is made. In the present instance, where the voltage across the reservoir condenser is zero or very low, little danger is likely to result, but in other cases, particularly where one is looking for a fault, there is always a danger that one of the condensers will not have been discharged, and if one inadvertently catches hold of, or places a hand across the two terminals, a very unpleasant shock may result.

For small powered sets this may be done with a screw-driver or piece of wire. Grasp the screw-driver by the handle, and place it in such a manner that the metal portion bridges the two terminals. If any charge is left, this will be discharged with a sharp spark, after which the circuit is safe to handle. With condensers working at more than 500 volts a sudden discharge in this manner may damage the condenser.[1] It is desirable, therefore, to use a resistance of a few thousand ohms in place of a direct short circuit. This operation must, of course, not be carried out while the circuit is still connected to the mains, but after the set has been switched off it is a very desirable precaution.

Modern sets use electrolytic condensers to a large extent. This class of component has a small internal leak, arising from the construction, so that it is self-discharging and the spark referred to will therefore be either small or non-existent.

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[1] The energy stored in a condenser is $\frac{1}{2} cv^2$, so that the danger of damage due to sudden discharge rises very rapidly as the voltage increases.

Voltage Tests. Reverting to our test, we have isolated all the remainder of the circuit, and we should now switch on the apparatus again, and once more test the voltage on the reservoir condenser. If it is now of a normal value (and as there is no load it will rise to the fullest possible value, i.e. 1·4 times the voltage on the secondary of the transformer), then the short circuit lies later on in the receiver, and we must examine the succeeding portions. It should be pointed out, however, that owing to the presence of this defect, the rectifier may have been damaged, and although it may behave satisfactorily on no load, it may still be found to give trouble when load is taken. After the fault has been remedied, therefore, it is desirable to check this point again, as will be seen later.

Let us assume, however, that the voltage is still low or non-existent. The next step is then to check the reservoir condenser. This may be done by disconnecting one side of the condenser, making sure that the circuit is otherwise unaltered. On switching on a voltage should now be developed across the output. The value will be reduced in intensity, but if any voltage now appears it indicates a faulty reservoir condenser. This should be replaced with a suitable equivalent. If, on the other hand, no voltage is obtained, even when the reservoir condenser is removed, it is probably the rectifier which is at fault.

This is more likely to be the case when the valve rectifiers are employed, as these will often lose their emission under overload. The rectifier should be tested, or preferably replaced and a further test made of the voltage output.

Transformer Faults. Transformer breakdown is not as rare as it should be, so that a brief discussion will not be amiss. The faults may be threefold:

(1) Disconnection in one of the windings.
(2) Overheating due to external overload.
(3) Overheating due to internal short circuit.

The first type of fault arises from a break in one of the lead out wires, or less frequently, from an actual break in the winding itself. It is shown up by the absence of voltage from the winding in question, and as a further check the resistance of the suspected winding may be measured with an ohmmeter (with the mains supply switched off) when an open-circuit indication will be obtained if the winding is broken. It is worth noting in passing that disconnections sometimes occur between the lead out wire and the terminal or soldering tag, and it is worth looking for such before condemning the transformer.

Overheating is evidence of overload, and is usually accompanied by a strong characteristic smell from the resin or wax with which the winding or the insulation is impregnated during manufacture. It is possible for such overload to arise from external causes. For example, if the insulation of one of the condensers, particularly the reservoir condenser, breaks down, there will be a short circuit across the system which will result in severe overload. (In such an event the rectifier also will almost certainly be destroyed.)

An external fault may be removed by disconnecting the transformer entirely. If it still runs hot, the fault is internal. If the fault now does not appear, the circuit must be checked for short circuits.

If the transformer still runs hot when all the secondaries have been disconnected the trouble is due to an internal short circuit, arising in all probability from a breakdown in the insulation either between windings or between several turns or layers of the same winding—the effect being referred to as "shorted turns."

Primary Current. A test on the primary current will always confirm this diagnosis. A normal transformer takes a small magnetising current even when not supplying a load, but this should not be more than about 15 per cent of the full load current. If it is more then the transformer is supplying some unauthorised load indicating an internal short circuit.

Full load current may be estimated by determining the wattage rating of the transformer and dividing this by the input voltage. If the wattage is not known, total the various loads. Thus a transformer supplying 250 volts h.t. at 30 mA, with two heater windings delivering 4V 2½A and 4V 3A respectively may be considered as delivering

$$(250 \times {\cdot}03) + (4 \times 2{\cdot}5) + (4 \times 3) = 29{\cdot}5 \text{ watts.}$$

If this is run off a 230V supply the primary current on full load would be about 130 mA, and the magnetising current should not exceed about 25 mA.

These calculations are not exact, but they indicate the order of current, which is sufficient for the purpose.

Smoothing Circuits. Reverting to the earlier tests, if it is found that the fault lies beyond the rectifier, and that when the remainder of the circuit is removed the voltage appears, the smoothing and voltage-dropping circuits must be gradually inserted one at a time, the voltage being measured at each point. The next step, for example, will be to connect the smoothing choke and smoothing condenser across the circuit. If the voltage is still present across both the condensers, this portion of the circuit is sound. If the voltage is present on the reservoir condenser, but not on the smoothing condenser, then there is a break in the smoothing choke. If the voltage across either condenser is zero, then there is clearly a short circuit across the smoothing condenser, and this condenser should either be removed and tested, or replaced by an equivalent condenser. We can continue in the same way to include each of the voltage tappings in the unit, bringing them in one at a time and noting whether the effects are normal or not. Any deviation from the normal expectation must be regarded as due to a fault until the reason is fully understood.

It should, perhaps, be pointed out that all the circuits in a mains unit of this type are interdependent. Suppose, for example, we have three output circuits, one normally giving 200 volts, and the other two giving 80 and 120 volts respectively. If we disconnect the 80 and 120 volt tappings, and connect only the 200 volt tapping with its appropriate load across it (e.g. connecting to the correct tapping on the receiver with which it is to be used) we shall find that the voltage on this tapping is more than 200. This is because we are not taking any load from the other two tappings, so that the total load on the power pack is less than usual. This, therefore, must not be considered as an abnormality.

The variation of voltage with load on a power unit varies considerably with different kinds of instrument, and depends entirely upon the resistance of the smoothing choke and the size of the reservoir condenser. A cheap power pack has what we call a bad regulation, in that the voltage falls very rapidly as we increase the current taken from the instrument, whereas a more expensive construction gives a more level characteristic.

L.T. Supplies. L.T. power packs are sometimes used, although to a limited extent. These are built on exactly the same lines as h.t. units, but the voltages dealt with are of smaller order. Electrolytic condensers, with a capacitance in the neighbourhood of 2,000 microfarads, are used for the reservoir and smoothing condensers, and the chokes are of relatively low resistance. Even so, the regulation is still bad and the voltage output varies considerably according to the current taken from the instrument. For this purpose a variable resistance is usually included in the instrument, together with a d.c. voltmeter, to indicate when the correct voltage is obtained. In adjusting any such instrument for correct operation on the receiver, it must always be used with the correct number of valves, and the rheostat must be controlled to give the right voltages on the valves. If any alteration is made to the number of valves in use, the voltage will be altered at once. A test for faults on such a circuit follows out exactly the same principles as already outlined for the h.t. unit.

A.C. Receivers. A.C. receivers enjoy considerable popularity to-day, and for these instruments special valves are often employed in which the customary filament is replaced by an indirectly-heated cathode. This comprises a metal cylinder coated with oxides which give off electrons profusely at a relatively low temperature. Running through the centre of this cathode is a small heater which is supplied with current from the a.c. mains at a low voltage. Modern receivers use valves with 6·3-V heaters taking 0·3 or 0·6 A, though older types use 4-V heaters taking 1 or 2 A. In order to avoid hum, the centre point of the heater winding on the mains transformer is connected to earth, as this avoids any considerable electrostatic effects. The cathode is made fairly massive so that it retains its heat and gives off a steady supply of electrons, despite the fact that the heater is carrying a fluctuating current.

Receivers incorporating such valves may be tested in exactly the same way as ordinary receivers, the cathode being considered as the filament in each case.

The output valve is often sometimes heated by raw a.c. at a potential of 4 volts or more according to type. In such cases the H.T.– connection is taken to the centre point of the l.t. winding on the transformer. The circuit otherwise behaves as a battery-driven arrangement.

Self Bias. A method of obtaining grid bias which is in very common use with the a.c. valves is the system known as self bias. With this arrangement the cathode of the valve is not directly connected to the H.T.— but is taken through a resistance. If we consider an isolated valve, such as that shown in Fig. 8.14, it will be seen that the anode current from the h.t. supply passes through the anode circuit, through the valve and then through this resistance to H.T.—. A voltage drop is, therefore, developed across this resistance, and as the H.T.— point is most negative in the circuit, the voltage drop on this resistance will be in the correct direction to provide grid bias. The grid circuit of the valve is, therefore, connected direct to H.T.—, thereby becoming a certain voltage negative with respect to the cathode. The value of the resistance chosen is such that the correct value of grid bias required is applied.

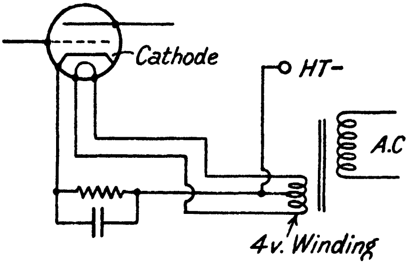


Fig. 8.14. Illustrating Method of Obtaining Self Bias.

We only require a steady voltage to be developed across this resistance, however, and we do not wish fluctuating currents to set up any voltage in the grid circuit. A large by-pass condenser is, therefore, connected across the grid bias resistance as shown in the figure. The value of by-pass condenser depends on the frequency of the current being handled. For r.f. or i.f. circuits a capacitance of 0·01 to 0·1 μF is usually adequate, though larger values may be necessary. For a.f. circuits a much larger capacitance is required, and modern practice usually employs electrolytic condensers of 25 or 50 μF. These are made in compact form, often tubular in shape and behave like

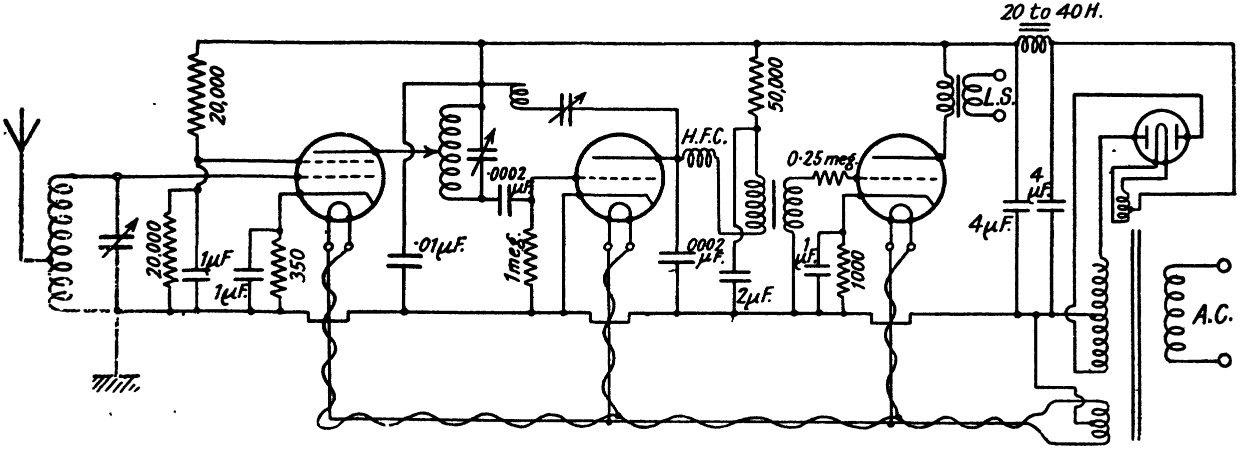


Fig. 8.15. Typical Straight Mains Receiver.

ordinary condensers except that they must be connected the right way round, with the positive pole to cathode. In any a.c. receiver this grid bias must thus be checked up on each valve in order to make sure that the valves are functioning under their correct conditions.

Fig. 8.15 shows a three valve straight a.c. receiver. A small negative grid bias is provided on the r.f. valve, and a larger bias on the a.f. valve. The grid leak in the detector valve is taken direct to the cathode, no grid bias being provided here. The examination of such a receiver for faults follows out the standard principles adopted with battery sets, and there is no need to outline the procedure in detail. If the fault is found to be due to the power pack, tests must be applied as given earlier in this chapter. The grid bias on each valve should be measured with a high-resistance voltmeter to see that it is of the right order, but otherwise the circuit, although apparently complex, requires no special treatment.

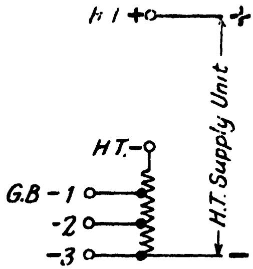


Fig. 8.16. Alternative Method of Obtaining Grid Bias.

In some cases grid bias is not obtained by making use of this special arrangement. Resistance is included in the negative h.t. lead, and tappings are taken on this resistance at suitable points. Such an arrangement is shown in Fig. 8.16, the principal feature being that each lead has to be filtered to avoid coupling between the circuits.

This system differs from the previous case in one particular. With self grid bias the voltage applied to the grid circuit of each valve is controlled entirely by the anode current flowing through the said valve. Hence, if for any reason a valve ceases to function, the remaining valves will not be seriously affected. In this second case the grid bias is controlled by the total anode current flowing in the circuit so that if one valve is not functioning, the grid bias applied to the other valves will be reduced owing to the smaller voltage drop produced by the decreased anode current.

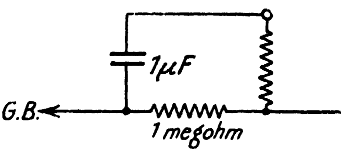


Fig. 8.17. Filtering on Grid Bias Circuit to Avoid Back-Coupling.

The filtering arrangements consist of a very high resistance, usually of the order of 1 megohm or more, with a by-pass condenser to earth as shown in Fig. 8.17. Since no grid current is actually flowing this high value of resistance is quite permissible, and acts as an effective choke against any audio-frequency current trying to flow through the grid-bias resistance. Such currents are immediately by-passed to earth by the condensers, thereby avoiding any coupling due to common resistance in the grid lead which is liable to cause trouble in the same way as a common anode resistance.

The bias resistor is often included in the connection between the negative ends of the reservoir and smoothing condensers, as in Fig. 8.18 (*a*). Still another arrangement is to utilise the inevitable voltage drop on the smoothing choke, designing this to give the requisite bias and including it in the negative lead as in Fig. 8.18 (*b*).

Sometimes a combination of both methods is employed, decoupling being added to the usual self-bias arrangement. This is often useful where hum is troublesome.

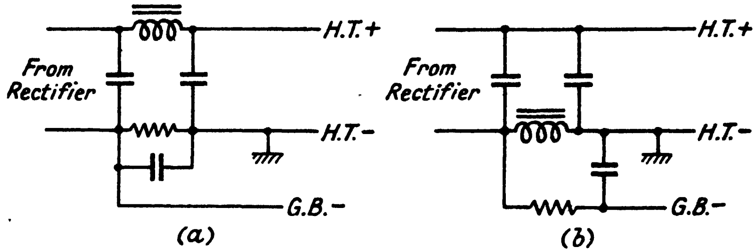


Fig. 8.18. Grid Bias may be obtained by Voltage Drop on a Resistance or Choke in the Negative H.T. Line.

Provision of Centre Tap. The point to remember in all these cases is that H.T.— is the most negative point in the circuit. The cathodes of the valves in the case of indirectly-heated valves are thus at a slightly positive potential, while in order to avoid hum the centre point of the heater winding is connected direct to H.T.—. In the case of directly-heated valves, the centre point of the heating winding is connected to H.T.— through the appropriate grid-bias resistance —so that while the grid circuit is connected to H.T.—, thereby obtaining the requisite negative voltage.

With directly-heated valves the grid voltage must always exceed the theoretical value by an amount equal to half the peak value of the a.c. heating voltage. Otherwise during certain portions of the cycle the grid bias will be insufficient, and we shall obtain grid current. Thus if we have in the last stage of an amplifier a valve having a 4-volt filament which normally requires 9 volts grid bias, we must arrange this grid-bias resistance to give an extra voltage of $2 \times 1{\cdot}4$, or say 3 volts for safety. Hence our total bias voltage must be 12 volts.

The actual value of grid-bias resistance is, of course, determined by dividing the voltage to be developed by the anode current flowing in the circuit, expressed in amperes. It is a useful rule to remember that a current of 1 milliampere flowing through 1,000 ohms causes a drop of 1 volt.

It is sometimes required to make a temporary (or permanent) centre tap on a filament winding. This may be done by connecting a centre-tapped potentiometer across the winding in question. Such a potentiometer, however, must be of low resistance (20 to 30 ohms only), as otherwise hum may be introduced into the circuit.

A.C. Hum. The problem of hum with a.c. receivers is in some respects less severe than with d.c. and in others more so. The very troublesome induction hum due to the positive earth or imperfectly earthed main which was mentioned in the d.c. case does not arise. Direct induction can occur, however, in the receiver itself—between the mains transformer and certain of the components. This is more particularly the case where the transformer is too small for its work so that the iron circuit is working at an abnormally high flux-density with consequent large leakage flux. The remedy is to shroud the transformer or move it farther away or dispose the components in some other manner.

Hum due to overworked transformers is often experienced with single-wave rectification. Here the iron circuit has to carry not only the alternating component of the current, but also the d.c., and the magnetisation of the iron is liable to be very unsymmetrical if the magnetic circuit is not generously designed. A case of this sort was experienced with a small two-valve set. The h.t. was obtained from a single-wave metal rectifier and the same transformer supplied the 4-volt heaters of the valves. No amount of extra smoothing on the h.t. side cured the hum, but the use of a separate transformer for the heaters eliminated it entirely. The trouble was that the transformer was much too small and the secondary wave-form was badly distorted in consequence.

While the average a.c. valve is quite satisfactory on a reasonably pure a.c., it is liable to give hum if the wave-form is "peaky" in character, which was the case in this instance.

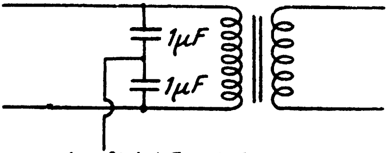
Hum due to imperfect smoothing of the rectified a.c. is fairly easy to detect. The earlier stages require more smoothing, while the output stage will tolerate several volts a.c. ripple without producing serious hum. Introduce extra smoothing circuits consisting of a choke and condenser into each anode lead in turn until a case is found where a marked diminution in hum is obtained. This is the faulty link. Alternatively, increasing the smoothing capacity by adding further condensers in parallel with existing ones will give a similar though less definite indication.

Induction. Induction hum can often be detected by short circuiting the primary of the a.f. transformer, or by connecting the grid of the last valve to G.B.—. If the hum disappears, we know that the hum is not in the last valve circuit. Now connect the grid of the preceding valve direct to G.B.—. If the hum disappears the trouble is in the earlier stages. If, as is more likely, the hum persists, it is due to poor smoothing on the last valve but one, or to induction on the a.f. transformer, if any.

A process of elimination must be adopted as always, but there is one important point to be remembered, namely, that the various circuits often affect one another to some extent. For example, a two-valve a.c. set having a directly-heated output valve with an indirectly-heated detector will often hum when switched on, becoming quiet in a few seconds after the detector cathode has warmed up. The load of the detector on the a.f. transformer stabilises the circuit.

Clearly, if the detector valve is removed the hum will become worse, and if we wish to isolate the detector circuit we must adopt some other method.

One way is to connect across the primary of the transformer a resistance equal to the a.c. resistance of the detector valve, which is then disconnected. This leaves the transformer operating under working conditions, but isolates the valve. If hum is still present it is due to direct induction on to the transformer which should be moved or altered in position. If the hum disappears it is probably due to insufficient smoothing in the h.t. supply to the detector.



Artificial Earth Point

Fig. 8.19. Form of Artificial Earth Often Useful with A.C. Sets.

Electrostatic induction may arise on grid leads, particularly with high values of grid leak. The remedy is to shorten the leads, reduce the grid impedance if possible, or alternatively run the grid leaks in shielded cable the outer casing of which is earthed.

Earthing makes a considerable difference to the hum. Failing a good earth, all zero potential points should be connected to H.T.—, including all the cores of the chokes, transformers, etc. If this point can be connected to earth as well, so much the better. A form of artificial earth which is often helpful is that shown in Fig. 8.19. Two 1 microfarad condensers are connected across the a.c. supply, and the centre point is treated as an earth.

Long leads in the detector circuit are to be avoided, particularly if they terminate at the far end in a high impedance. Some gramophone pick-ups are very troublesome in this respect.

Quality of Hum. Hum on most receivers will be found to be a mixture of 50 and 100 cycle components. The former arises from induction (including electrostatic induction into the cathode circuit from the heaters) while the latter is due to insufficient smoothing on the h.t. chain (assuming double-wave rectification or its equivalent). The final hum is a balance between all the various hum sources and the set must be considered as a whole in relation to its ultimate criterion—the hum in the output stage. Only if this is bad does it become necessary to commence looking for sources, and even when this is done it is usually unnecessary to reduce the various sources completely to zero, because of the cancelling effect which is almost inevitably present.

An oscilloscope is of value here since it shows whether the hum is mainly 50 or 100 cycle and thus gives a clue to its source. Use the set in its working condition but with no applied signal. The hum may then be amplified, using the amplifier in the oscilloscope, so that its quality can be examined.

Modulation Hum. A form of hum which is sometimes obtained tunes in on the carrier wave of the signal, the set being quiet when no station is being received. This is a high-frequency disturbance due to a bad earth or difference of potential between the earth connection on the receiver and the earthed pole of the mains. There is a further type of modulation hum due to self-oscillation at a high-frequency in the circuits associated with the rectifying valve, where such is used.

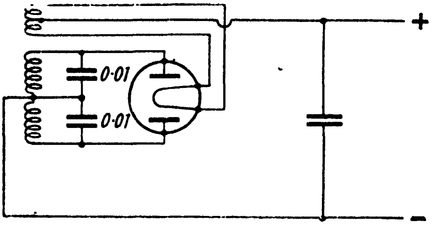


Fig. 8.20. Method of Curing Modulation Hum.

Both these troubles produce the same general effect and several cures are possible, one of the most effective being the connection of a ·01 μF condenser across the secondary of the mains transformer. Where double-wave rectification is used a condenser must be connected across each half of the h.t. secondary as shown in Fig. 8.20.

Another cure is to connect a condenser between one side of the mains and earth or chassis as in Fig. 8.21. This condenser should

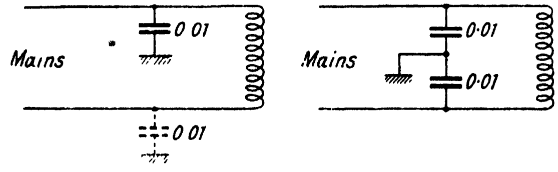


Fig. 8.21. Alternative Cures for Modulation Hum.

not exceed ·01 μF and should be smaller if possible. Otherwise there is a danger of shock if one removes the earth wire from the receiver, since the chassis then becomes live. Alternatively two such condensers may be used in series across the mains, the centre point being earthed.

Another source of difficulty is the use of a high impedance in the grid circuit of an r.f. or detector valve. A case in point was a circuit in which the tuning coil was connected to H.T.— through a

·01 μF condenser. In order to provide a direct-current path between grid and cathode, a leak of 1 megohm was connected across this condenser. The circuit gave unpleasant modulation hum which was not cured until the value of the leak was reduced to 0·1 megohm, under which conditions the circuit worked perfectly satisfactorily without the hum.

In exceptional cases hum may be due to bad smoothing on the screen or grid bias resistance of the r.f. valve, in which case the remedy is obvious, while cross modulation may also cause hum to build up on a strong carrier, but not on a weak one. The remedy in this latter case is to reduce the r.f. input or use a different valve.

Universal Receivers. The latest development in mains technique is the introduction of sets which will operate from either a.c. or d.c. mains without any alteration. Such receivers use d.c. technique for the most part. The valves used are the so-called universal type taking 0·3 amps. at 6·3 volts or a multiple thereof, and the heaters are wired in series and connected straight across the mains in series with the customary breaking-down resistance. Since the valves are indirectly heated it is immaterial whether this heating current is a.c. or d.c.

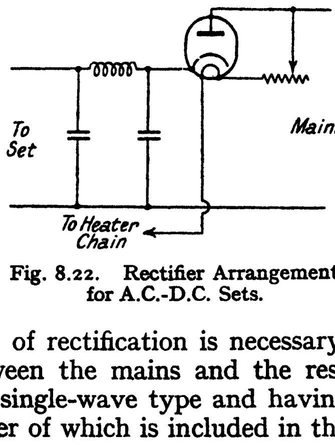


Fig. 8.22. Rectifier Arrangement for A.C.-D.C. Sets.

The high-tension supply, however, requires slight modification, for if an a.c. supply is being used some form of rectification is necessary. A rectifier is, therefore, inserted between the mains and the rest of the set, this rectifier being of the single-wave type and having an indirectly-heated cathode, the heater of which is included in the same chain as the rest of the valves. Following this rectifier is a reservoir condenser, feeding a smoothing circuit in the normal manner, the h.t. supply to the set being taken from the output of the smoothing chain in the usual fashion.

It is clear that the use of this rectifier will not prevent the set from working on d.c. supply, provided that it is the right way round. Therefore, if the plug is inserted into the mains socket in the correct direction the receiver will work. With an a.c. supply, of course, the receiver operates whichever way round the plug is inserted. Fig. 8.22 shows the rectifier arrangements for a universal receiver. The remainder of the circuit would be similar to that of a d.c. receiver, and the test for faults would follow the lines already set down.

The use of 6·3 volt valves arose from the introduction of car radio receivers which use the 6 or 12 volt car battery for power supply. The valves have proved so convenient that they are rapidly being standardised both for normal a.c. receivers and for universal sets.

6·3 volts 0·3 amps provides a heater power approaching 2 watts, which is sufficient for normal valves. Where a higher slope or greater output is required the heater wattage must be increased. For a.c. receivers this is done by increasing the current, keeping the voltage at 6·3, since the valves are all connected in parallel.

For universal receivers where the valves are in series, the current must remain the same so the voltage is increased to 13 or even 26 volts. This means special valves but this is not a serious disadvantage because in any case valves for universal receivers must be designed to work with low anode voltages since the mains supply is only 200/250 volts, leaving only some 180 to 200 volts d.c. after rectification and smoothing.

CHAPTER IX

SHORT-WAVE TESTS

WHEN testing a receiver having one or more short-wave ranges, the same technique is applied with due regard for the effects likely to result from the higher frequency.

As with normal sets, the majority of receivers use superhet principles though there are a number of simple straight detector—l.f. sets in use. It is useful to consider such circuits in detail because the only points of difficulty will occur in the tuning circuits which will be of similar form whether the set is straight or superhet.

Consider the circuit of Fig. 9.1, which shows a simple reacting detector. It is often found with this class of circuit that reaction is difficult to obtain. Increasing the reaction turns is only a partial cure because a point is quickly reached where the tune of the reaction circuit comes within the range of the grid circuit and prevents the system from tuning down to its proper wave-length.

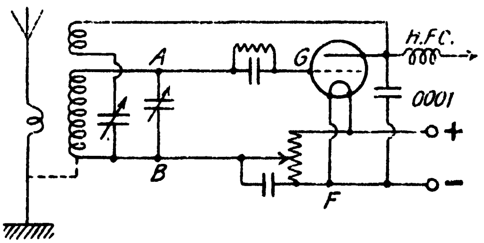


Fig. 9.1. Typical Short-Wave Circuit.

The reaction turns should not be more than about one third to one half of the grid turns. If this does not produce adequate reaction the reason is in the wiring which will almost certainly be found to contain loops having an inductance comparable with that of the reaction coil itself. The point is discussed further on page 159. Hence until one reaches frequencies of 20 Mc/s or more there is no need to treat short-wave circuits as being different from normal. Above 20 Mc/s transit time effects begin to become troublesome and some special precautions may be required, as discussed later.

Another fallacy which is very prevalent is that low-loss tuning arrangements are essential. Whether this is the case or not depends on what is meant by low-loss. The losses which are of importance at very high frequencies are the conductor losses and eddy-current losses. The dielectric losses are of secondary importance, in fact, less important than they are on normal broadcast wave-lengths. Therefore, if one finds the coils wound on ordinary solid former, do not immediately rush to the conclusion that the losses are too heavy. The important factors are that the turns on the coil should be spaced apart by a distance equal to at least the diameter of the wire, and the wire should be copper or silver-plated copper—not nickelled or tinned.

By-Pass Arrangements. These points have been dwelt upon, because considerable time can be wasted in altering a circuit unnecessarily. The production of oscillation at short wave-lengths is a relatively simple matter, and is controlled by far more ordinary causes than one would suppose. Perhaps the most common source of trouble is the failure to provide an adequate path for the high-frequency currents after they leave the tuned circuit. Let us return once again to Fig. 9.1. In the grid circuit we have a potentiometer across the filament in order to obtain the best rectifying point, so that the reaction shall be smooth. A high-frequency current has to pass from the tuned circuit to the grid and filament of the valve along the two feeder lines *AG* and *BF*. It will be clear that in the line *BF* we have the resistance of part of the potentiometer, and this may offer sufficient impedance to the current to prevent the circuit from oscillating. A condenser should, therefore, be placed between the point *B* and the negative filament lead as shown. A condenser from the anode of the valve to L.T.— will again assist the detector to function properly, and will often cause the circuit to oscillate rather than prevent it.

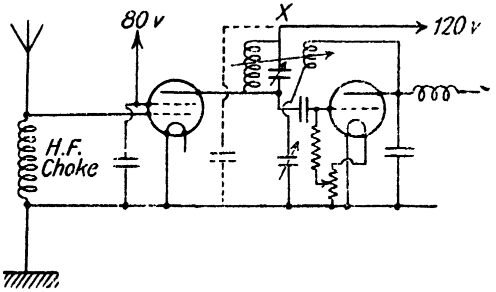


Fig. 9.2. Short-Wave Circuit with R.F. Valve.

Fig. 9.2 shows a tuned-anode circuit; although the amplification on these wave-lengths is usually small, the advantages gained from a radio-frequency stage are often of value. Reaction in this case is applied from the detector valve on to the tuned-anode circuit, and it will be found imperative to connect a by-pass condenser across from the point *X* to L.T. —. It may be that the particular set already has a large condenser across the h.t. battery, but as explained in a previous instance, this will not be sufficient. The inductance of the lead running from the tuned circuit to the h.t. terminal will often be sufficient to prevent the circuit from oscillating, and the by-pass condenser must be connected from the tuned circuit itself to the negative side of the filament of the detector valve, using as short a lead as possible.

These two instances will serve to exemplify the differences in procedure arising from the very high frequencies, and these remarks, coupled with what has been said in previous chapters dealing with tuning and r.f. amplifying circuits, should enable the reader to overcome any difficulties which may arise. Make sure that the high-frequency energy has an easy path, remembering that the inductance of a short length of lead is quite appreciable at these high frequencies. As a matter of fact a length of wire 10 centimetres (4 ins.) long and 1 millimetre diameter has an inductance of 0·1 μH, and this at a wave-length of 20 metres has an impedance of approximately 10 ohms, so that although its high-frequency resistance is a small fraction of an ohm, such a wire would present appreciable impedance to the high frequencies with which we are dealing.

Tuning Difficulties. This leads to the second of the difficulties usually encountered in short-wave practice, that of obtaining satisfactory tuning. This point is also wrapped up with the production of oscillation, for in certain cases a badly conceived layout will not only give a poor tuning range, but will prevent the circuit from oscillating, a matter of importance when dealing with superhet oscillators.

Perhaps the principal feature of short-wave reception is the very small inductances which have to be employed. In order to tune to resonance with a condenser of ·0001 microfarads, at a frequency of 15 million cycles per second (20 metres) we require an inductance of 1·2 microhenries only. This is obtained by using two or three turns of wire on a relatively small diameter former, the turns being well separated in order to minimise conductor loss as was mentioned previously. We have already shown that a length of 4 ins. (10 centimetres) of wire has an inductance of 0·1 microhenry, which is nearly 10 per cent of the total inductance of the circuit. It is quite possible to arrange the coil some distance away from the tuning condenser, so that leads considerably in excess of 4 ins. have to be used. This might easily increase the total inductance in the circuit so much that the circuit would not tune down to the wave-length for which it was intended.

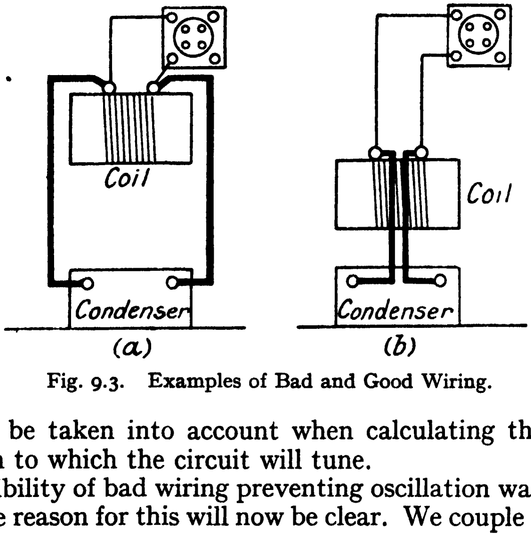
So far we have only considered the inductance of a straight wire, but if we arrange our wires so that they enclose an area the inductance is increased. In practice it is quite an easy matter to double the inductance by bad wiring, so that a circuit intended to tune say 15 metres would actually refuse to tune below about 25 metres.

Such a trouble is illustrated in Fig. 9.3, where the oft-quoted advice to keep the grid leads short has been followed out. The lead between the coil and the grid of the valve is undoubtedly very short, but actually the tuned circuit does not only consist of the coil and the condenser, for the closed loop shown in heavy line is also within the tuned circuit, and probably has an inductance comparable with that of the coil itself.

The arrangement is thus a bastard one consisting of an inductance in parallel with a similar inductance and a condenser, in series. The tuning will certainly be far from orthodox and will include at least one dead spot.

The circuit correctly arranged is shown in Fig. 9.3 (*b*), where the leads between the coil and the tuning condenser are as short as possible, and are run relatively close together (not less than ½ in. apart, in order to avoid excessive capacitance), while relatively long leads are taken from the tuned circuit to the grid. Such practice is preferable for, although long leads to the grid may cause a small loss in voltage, they do not affect the tuning properties of the circuit.

Hence, if the circuit does not tune down to the nominal wave-length, the layout is the first thing to suspect. If the coil has the correct inductance, then with a proper layout of the circuit, it must tune to its nominal minimum without difficulty. The valve, valve holder, and variable condenser all combine with the wiring to give a minimum capacitance in the neighbourhood of 50 pF; this capacitance must be taken into account when calculating the minimum wave-length to which the circuit will tune.



(a) (b)

Fig. 9.3. Examples of Bad and Good Wiring.

The possibility of bad wiring preventing oscillation was mentioned earlier. The reason for this will now be clear. We couple our reaction coil to the tuning coil in the circuit. We have seen that it is not desirable to increase the reaction turns to a value much in excess of half the number of turns on the tuning coil. Clearly, if the circuit wiring is so constructed as to introduce an extra inductance of the same order as that of the tuning coil, our reaction winding is no longer coupled to the whole circuit, but only to a part thereof. Under such circumstances reaction may be difficult to obtain. On re-wiring the circuit as already discussed, the reaction coil will couple to the whole inductance in circuit, and this will probably be found to cure the difficulty.

The possibility of the reaction coil affecting the tune has also been referred to. If the number of turns on the reaction coil is excessive, it will prevent the circuit from tuning to its proper minimum. This more particularly is the case where, owing to bad construction or insufficient by-passing in the rest of the circuit a large amount of reaction capacitance has to be employed in order to make the circuit oscillate.

Suppose, for example, that we have 4-turn coil tuned with a condenser of 100 pF, including valve and circuit capacitance. Let us assume that the reaction coil has 2 turns, but that owing to bad construction the reaction condenser has to be increased to 300 pF (·0003 μF) before the circuit oscillates. Now the tune of this reaction circuit is distinctly higher than that of the grid circuit, and it will be found impossible to tune the circuit below the wave-length at which the reaction circuit resonates.

Therefore, not only must the reaction turns be kept small, but the circuits must be carefully constructed so that only a relatively small value of reaction condenser is necessary. Various ways of making the circuit oscillate easily have already been discussed, and attention to these points will usually result in the circuit behaving in a satisfactory manner. Many of the points discussed have been largely matters of design, but the peculiar difficulties encountered with short-wave sets usually arise from defective design or construction.

Threshold Howling. A form of difficulty often experienced in short-wave receivers is known as "threshold howling," or "squegging." The successful operation of a short-wave set depends largely upon a very smooth and progressive reaction control. It may be found that just when the detector is on the threshold of oscillation, it sets up an unpleasant growl or shriek which entirely blots out the reception, while if we are dealing with a superhet any squegging of the oscillator will modulate the i.f. output and produce an unpleasant continuous howling noise.

This unpleasant state of affairs is due to a change in the constants of the circuit which takes place immediately the set is made to oscillate. The effect of this change momentarily pulls the set out of oscillation until conditions have readjusted themselves, when it will commence to oscillate again. Such a trigger action, equivalent to the mechanical operation of an electric bell, causes a squeal or growl having a frequency equal to the number of times per second the set falls in and out of oscillation.

A simple remedy, which is usually effective, is to introduce a resistance in the anode circuit of the detector valve. A value of 10,000 ohms is usually sufficient. With a grid detector the anode current falls when the circuit oscillates, and this causes a decreased voltage drop on the resistance. Hence the anode voltage on the valve rises, and holds the circuit in oscillation. If the trouble arises with a superhet oscillator the best remedy is to reduce the value of grid leak. A value of a few thousand ohms may be necessary and is quite satisfactory, because the effective grid impedance of the valve will be low in any case.

Flat Spots. In tuning a short-wave receiver, one often encounters effects known variously as "flat spots," "dead spots," "holes," "beetles," etc. The circuit refuses to oscillate, or requires a considerable increase in the reaction setting, at certain points of the dial. This is due to some absorption effect which must be located and removed if the trouble is to be overcome.

The most prolific source of this absorption is the aerial circuit. It may be that the wave-length being received coincides with a harmonic of the natural wave-length of the aerial. The difficulty is removed by altering the natural wave-length of the aerial by inserting a small series condenser. A value of ·0001 μF is quite sufficient. The difficulty is more pronounced with long aerials and better reception all round is obtainable on short wave-lengths with a small aerial.

The introduction of a condenser in this manner may introduce a flat spot on some other wave-length. In some cases it is possible to arrange matters so that the aerial does not interfere with reception at all, but if this desirable state of affairs cannot be attained, arrangements must be made for inserting or removing the fixed condenser at will.

If the aerial circuit is not found to be the cause of the trouble, then one must examine the receiver for possible closed circuits. It may be that certain other portions of the circuit constitute a completely closed inductance of relatively large dimensions, and this may resonate on some wave-length within the tuning range, and hence absorb energy. Particularly in a case where one is using some sort of framework or chassis this effect must be looked for. There is a possibility that some nearby circuit is causing an absorption effect, although this is rather rare.

Flat spots arising from a bastard tuning circuit as in Fig. 9.3 (*a*) are also frequently found. Such a circuit is a form of coupled circuit which at any setting provides not only a tuning point but also an absorption point, and this can only be avoided by rearrangement of the wiring.

Short-Wave Wavemeters. Some reference may be made to the method employed for checking the tuning with this class of receiver. An absorption wavemeter is usually employed. This consists of a simple tuning circuit comprising a coil tuned with a variable condenser, the wave-length of the combination being determined according to the reading on the condenser dial. This wavemeter is brought near the circuit under test (within two or three inches) and the condenser is gradually rotated until the absorption takes place.

The absorption is best observed by allowing the receiver circuit to oscillate gently. When the wavemeter comes into tune, the circuit will cease to oscillate over a few degrees of the wavemeter dial, and will recommence to oscillate as soon as the wavemeter is mistuned again or removed. The wavemeter is then moved farther away and the process is repeated until the absorption only spreads over a degree or so. From the reading on the wavemeter the wave-length of the circuit can then be determined.

The circuit should be only just oscillating, as otherwise the wavemeter will have to be placed too close to the circuit in order to stop the oscillation, and this leads to inaccuracies. Moreover, the wavelength of the circuit in the oscillating and non-oscillating condition is not the same unless the circuit is only just oscillating.

This form of test is particularly useful for checking superhet oscillators. For ordinary tuning tests a signal generator may be used. Modern instruments invariably include ranges up to 10 and usually 25 or 30 megacycles.

Ultra Short-Waves. At frequencies above about 20 megacycles troubles begin to occur due to the fact that the time taken by the electrons to move between the electrodes of the valves is comparable with the period of the oscillation. To counter this, special technique is adopted in the manufacture of the valves.

It is impracticable to discuss this subject in detail because the technique is highly specialised. The point is that the modern broadcast receiver often contains wave ranges which are beginning to encroach on these border line conditions, and peculiar effects may be observed in consequence.

The principal result of this transit time effect is to reduce the input impedance (between grid and cathode) of the valves in use to some quite low value often as little as 10,000 ohms. This clearly reduces the Q of the tuned circuits very seriously and may make oscillation difficult. The step-up of the aerial stage may also be reduced to unity or less, though measurements at these high frequencies are beyond the scope of normal service equipment.

Some improvement may be obtained by tapping the grid down the coil. Tapping half-way down will reduce the damping to one-quarter, which may allow the circuit to develop nearly four times its previous voltage, so that although we are only using half the total voltage we are twice as well off as before.

CHAPTER X

RECEIVER TESTS

HAVING discussed the apparatus essential for testing the amplification of various parts of the receiver we may discuss the application of this equipment to complete receiver tests. The Year Book of the Institute of Radio Engineers for 1931 contained the first standard recommendations on this subject which can conveniently be quoted here. A similar series of recommendations has been prepared by the Radio Manufacturers Association of Great Britain. The reader would be well advised to obtain a copy of these for himself.[1] The tests suggested are:

1. *Sensitivity*. Voltage is applied to the receiver from a signal generator, and is adjusted in intensity until an output of 50 mW is developed across a resistance inserted in place of the loud speaker, this resistance being made equal to the resistive component of the voice coil impedance. The radio frequency shall be modulated to a depth of 30 per cent at 400 cycles per second. This test is carried out at a number of standard carrier frequencies.

2. *Selectivity*. This is the degree to which the receiver is capable of differentiating between signals of different frequency. The I.R.E. specification requires that the receiver be tuned to one of the standard test frequencies, and the input adjusted until the normal test output (50 mW) is obtained. The signal generator is then mistuned by an amount not exceeding 10 kc/s, and its strength adjusted until the normal test output is again obtained. The readings are continued in steps not exceeding 10 kc/s on each side of the tuning point until the radio-frequency input is at least 100 times the value at resonance, or until a range of 100 kc/s on either side of the resonant point has been covered. The arrangement, of course, gives an inversion of the customary resonance curve.

The R.M.A. proposes a more elaborate test involving two signal generators with their outputs connected in series. One of these provides a normal and the other an interfering signal. The receiver is first tuned to the interfering signal, which is set to 1 mV and modulated at 400 c/s to a depth of 30 per cent.

The volume control is then set until the receiver delivers ¼ of its normal output and the second signal generator switched on and adjusted to the same frequency as the first by the method of zero beat. The output of this generator is also set to 1 mV, but unmodulated.

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[1] *Specifications for Testing of Broadcast Receivers.* Two parts, each 2*s.* 0*d.* Obtainable from the Radio Manufacturers Association, Astor House, Aldwych, London, W.C.2.

The interfering signal is then detuned by suitable increments, commencing 5 kc/s off tune. The output obtained is that due to the *interfering* signal and the setting of the interfering signal generator is adjusted until this output is 40 dB below the original output (one quarter nominal output). This is repeated for various increments of mis-tuning, the result being an inverted resonance curve as before.

This method is employed as being a better reproduction of the actual conditions which the set is required to handle in practice. A filter should be included in the output to remove all frequencies other than the 400 c/s modulation to avoid errors due to hum or harmonics.

3. *Fidelity.* The receiver is tuned to one of the standard test frequencies, and the input is adjusted to give normal test output on the receiver. The modulation is then varied in suitable steps from 40 to 10,000 cycles per second, the percentage of modulation being maintained constant at 30 per cent. The output obtained in each case is noted and the results are plotted as a percentage of the output obtained with the standard 400 cycle modulation.

The R.M.A. specification suggests two further tests as under:

4. *Noise.* This is defined as the r.f. carrier input (unmodulated) for which the r.m.s. noise output is equal to that given by a carrier modulated to a depth of 10 per cent at 1500 c/s. The test is made by applying a signal modulated in this fashion, the strength being adjusted until switching off the modulation causes the reading on the output meter (in watts) to be halved. This input is then the noise level.

Accurate tuning is essential, and the output meter should have a characteristic level within ± 2 dB from 500 to 8000 c/s. A filter should be incorporated to cut off frequencies below 100 c/s to discriminate against hum.

5. *A.V.C.* For this test the receiver is fed with a signal of 1 volt, modulated 30 per cent at 400 c/s and the volume control is adjusted until the output is ¼ of nominal output. The input is then reduced to zero in suitable steps and the reading of the output meter noted.

Apparatus Required. The apparatus employed should be as simple as is consistent with accurate performance of the necessary functions. As far as possible, the same apparatus should be used in different tests. The values of the electrical quantities and the calibrations should not change with time; or if some change is unavoidable, means for checking should be provided.

The requirements are briefly as follows:

1. *Audio-Frequency Source* (whether separate or part of 2). The total harmonic content in the output of this oscillator should not exceed 5 per cent. It is arranged to modulate the radio-frequency oscillator by a known amount, and preferably should furnish the

same degree of modulation without readjustment at all carrier frequencies and all modulation frequencies.

2. *Radio-Frequency Source.* This consists of a valve oscillator, either fully shielded in itself or so shielded from the radio receiver under test that there is no direct radiation to the receiver. The frequency should be adjustable, and should not be affected by changes in output power. An "incremental" control is desirable providing a small variation on either side of the normal setting.

The output should be variable from 1 μV to 1 V with an accuracy of ± 10 per cent up to 10 Mc/s and ± 25 per cent above. The frequency calibration should be within 1 per cent (and within 0·5 kc/s on the incremental dial) and the modulation accurate to within ± 1/10th of the nominal value.

3. *Output Measuring Circuit.* The components of the output measuring circuit should be as follows:

(*a*) A non-inductive load resistor adjustable by calibrated taps and covering a range of 1 to 20,000 ohms and capable of dissipating 0·1 watt at any setting.[1]

(*b*) An output filter to be used with radio receivers normally having d.c. in their outputs. A recommended form consists of an inductance of not less than 50 henries (with 50 milliamperes d.c. in the winding), and a capacitance of not less than 8 microfarads arranged as shown in Fig. 10.1.

(*c*) A valve voltmeter or an equivalent device which will measure accurately the r.m.s. values of output voltage or alternatively, the current through the resistance.

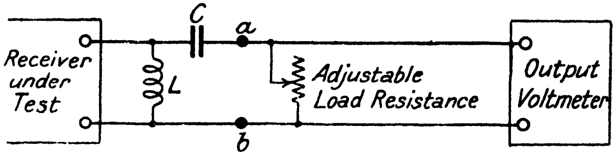

Fig. 10.1. Choke-Output Arrangement for Avoiding Direct Anode Current in Output Circuit.

Input Measurements. (*a*) *Radio Receiver without a self-contained aerial.* The method of introducing the input with a normal receiver

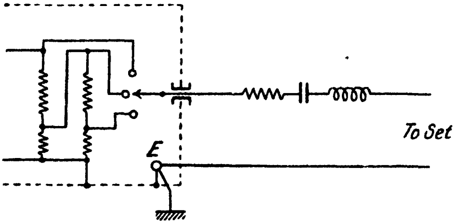

Fig. 10.2. Connection of Dummy Aerial to Attenuator.

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[1] This is for a 50 milliwatt output. If greater outputs than this are to be measured the rating of the resistance must be increased.

is indicated in Fig. 10.2. The radio-frequency current from the oscillator is passed through a resistance via an attenuator so that the voltage developed across the said resistance is accurately known. This voltage is introduced into the dummy aerial circuit, the constants of which are as specified previously, viz. ·0002 μF, 20 μH and a total resistance (including the attenuator) of 25 ohms.

These values were chosen in the days before short-wave operation became common. It is customary at these higher frequencies to use a simple resistance of several hundred ohms as a dummy aerial, since this more accurately represents the behaviour of an actual aerial. The R.M.A. specification calls for a network of the original form (L, C and R) up to 2 Mc/s and a simple 400 ohm resistance above this frequency.

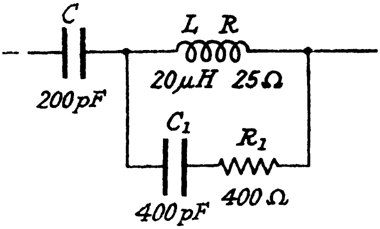

Fig. 10.3. Dummy Aerial Network to cover both Medium and Short Waves.

It is common to employ a network of the form shown in Fig. 10.3. At low frequencies the reactance of C_1 is high so that the shunting action of C_1R_1 is negligible and the network behaves as a 200 pF condenser in series with 20 μH and 25 ohms. At high frequencies, however, the reactance of both C and C_1 is small, while that of L is high, so that the network behaves as a simple 400 ohm resistance.

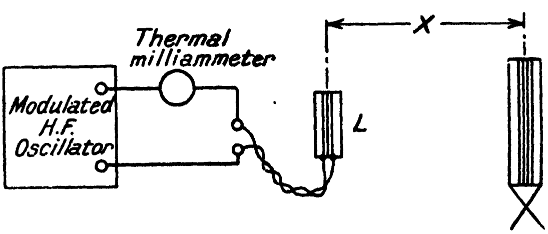

Fig. 10.4. Arrangement with Frame Aerial.

(*b*) *Radio receiver with a frame aerial.* This form of input circuit is seldom used, but it is almost essential when dealing with frame aerial receivers, the arrangement being as in Fig. 10.4.

A known radio field intensity is impressed on the frame by adjusting the distance X and the current through the coil L. The coil and frame centres are kept on a common axis, and the distance X kept large as compared with the dimensions of the frame.

The radio field intensity is:

$$\mathcal{E} = \frac{18{,}850\,NA^2I}{(A^2+X^2)^{3/2}}\,cos\ B \text{ microvolts per meter, where}$$

N is the number of turns in the coupling coil L;
A is the radius of the coupling coil, in centimetres;
I is the ammeter reading in microamperes;
X is the distance in centimeters between the centre of the coupling coil and the centre of the frame aerial; and
B is the angle, if any, between the axis of the frame aerial and the line between coil centres.

The voltage induced in the frame is obtained by multiplying this field strength by the effective height of the frame, which is given approximately, for a rectangular frame, by the expression:

$$h = 2\,N\,H\,sin\ \frac{\pi f\ S}{300{,}000} \text{ meters, where}$$

N = the number of turns;
H = the height of the loop in metres;
S = the length of the loop in metres, and
f = the frequency in kilocycles.

Alternatively, the radio-frequency voltage may be introduced into the frame circuit by inserting the terminal impedance of a resistance-type attenuator in series with the frame at a point of earth potential in a manner similar to that shown for an artificial antenna in Fig. 10.2. This method has the disadvantage that it means breaking into the set. The impedance of the attenuator must, of course, be small compared with that of the frame, which is itself only a few ohms.

Output Measurements. The output is measured by noting the current through or voltage across a suitable resistance in the loudspeaker circuit. The circuit of Fig. 10.1 shows the latter arrangement in conjunction with a choke-output filter, but a measurement of current, preferably with a thermo-couple of thermal meter, is just as good and somewhat more convenient.

The value for R is dependent on the operating conditions of the output valves used in the radio receiver and is arbitrarily taken as the optimum load resistance specified by the valve manufacturer for maximum undistorted output power under the given conditions.

In the case of a radio receiver having an output transformer, R is evaluated in terms of the equivalent primary resistance, so that

$$R = \frac{R_p}{A^2}, \text{ where}$$

A = the transformer ratio of primary to secondary turns; and
R_p = the optimum load resistance specified by the makers for the particular output valve employed.

The voltage across R for an output of W watts is $V = \sqrt{W/R}$ while the current $I = \sqrt{W/R}$.

There are on the market a number of output meters comprising a transformer, load resistance and meter. The load resistance is fixed, which enables the meter to be calibrated direct in milliwatts, while the transformer is provided with a number of tappings, selected by a switch or by plugging into an appropriate socket, so that the effective primary impedance can be varied to suit the valve in the receiver.

These instruments are very convenient. The better grade ones employ a thermal meter which must be used with caution, for such meters burn out on quite small overloads. For service and works testing a rectifier instrument is usually used which, while less accurate and subject to frequency error, is of better value on account of its greater robustness.

Allowance for Hum. The voltages due to a.c. hum, valve noises, etc., that may exist across the output of some radio receivers must be considered where the output voltage to be measured is small. For example, if these voltages are comparable with the normal test output voltage, the voltage across the resistor R for normal test output must be:

$$V = \sqrt{V_1^2 + V_2^2}, \text{ where}$$

V_1 is the r.m.s. voltage due to extraneous effects, and

V_2 is the value for normal test output voltage which gives 0·05 watt power in R.

A similar expression applies for current measurements.

Representative Values. For purposes of comparison some representative figures are given in Table VI overleaf. The first results were taken on a representive 3-valve receiver of the S.G., Det. L.F. type, using battery valves and a triode in the output stage.

The second set of results refers to a modern 5-valve mains-driven superheterodyne having an h.f. stage, frequency changer, i.f. stage, diode detector and high-slope output pentode.

The equivalent field strengths (microvolts per meter) are obtained by dividing these figures by the assumed effective height of the artificial aerial, namely 4 metres.

Sensitivities of the order of 10–20 microvolts are adequate for broadcast conditions.

Modern communications receivers have greater sensitivities of 1 microvolt or even less. Greater sensitivities are not possible with normal amplitude modulation owing to "background" noise generated by the set itself.

It is worthy of note that the R.M.A. specification stipulates that when testing battery sets all batteries shall show their nominal voltage and that the internal resistance of the h.t. battery shall be increased by adding a resistance of 1 ohm per cell in the negative lead.

TABLE VI

TYPICAL RECEIVER PERFORMANCES

(*a*) 3-valve battery set

Wave-length (meters).	Input (microvolts) to give normal test output (50 mW.).	
	With zero reaction	With full reaction
250	1,100	95
375	1,900	190
500	3,200	380
1,300	830	110
1,800	1,700	250

(*b*) 5-valve mains superheterodyne

Wave-length (meters).	Input (microvolts) to give normal test output (50 mW.).
250	12
375	15
500	24
1,300	30*
1,800	40

Fidelity Tests. The general requirements for fidelity Tests have already been mentioned, and the conditions specified are largely self explanatory. The receiver is supplied with r.f. at a constant modulation depth, but the frequency is varied over the audio-frequency range. The output is noted on a suitable meter.

For a complete test the reading is taken in the loud speaker circuit, using a resistance load, but for special purposes the output may be measured at other parts of the receiver, e.g. immediately following the detector.

The test is made at normal test output since the fidelity (i.e. the frequency response) is, or should be, independent of the actual strength of the input.

Special Tests. The measurements specified above are the customary routine tests necessary to obtain data on the performance of the various receivers for purposes of reference. From time to time the individual reader will require to make special tests of his own, such as overload or detector characteristics, automatic gain control tests, etc. It is not necessary to detail any such tests as the requirements vary, and the method of attacking the problem is also dependent upon the conditions, but from the ground work built up so far methods may speedily be devised to meet any specified requirement.

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* The lower sensitivity here was deliberate and arises from the use of an under-coupled r.f. transformer on the long waves to obtain increased selectivity.

The R.M.A. has prepared a series of tentative acoustic tests on receivers. This, however, involves technique which, in the author's view, is beyond the scope of normal receiver testing and no detailed review of these proposals is included here.

The proposals, however, constituting Part 2 of the standard tests, are worthy of study by the radio engineer concerned with acoustic performance.

CHAPTER XI

COMPONENT TESTING

IN following out the methods outlined in the preceding chapters of this book, the reader will often be faced with the necessity for making some form of test on a particular component in order to determine whether it is working satisfactorily or not.

This chapter contains a brief description of some of the tests likely to be required, commencing with simple tests requiring a minimum of apparatus and introducing later on specialised tests more suitable for the laboratory.

The methods described are not the only ones, nor are they of a precision character. They are practical forms of test capable of giving results to a sufficient order of accuracy for normal set testing.

RESISTANCE TESTING

Continuity. One of the simplest tests required in practice is a continuity test. This may very simply be done by means of a voltmeter and a battery of 1½ to 4½ volts. If the circuit is "through" the voltmeter will read. The reading may be slightly less than the full amount due to the voltage drop in the circuit, but this is immaterial since the test is purely qualitative.

Measuring Resistance. A simple continuity test, however, is of limited application. In many cases it is necessary to ascertain the resistance of a given circuit. A simple example is the case of a dual-range coil. In the long-wave position the resistance will, of course, be distinctly greater than on the short waves, owing to the larger number of turns of wire. A continuity test would fail to discriminate between the two.

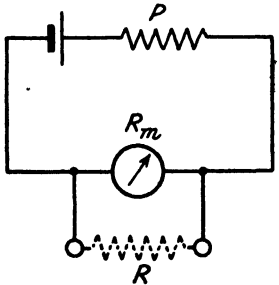


Fig. 11.1. Circuit for reading Low Resistances.

For such purposes an ohmmeter is used. The operation of this instrument was discussed on page 14, and such meters have now come to be regarded as an essential part of radio-testing equipment. The method serves for the greater part of the tests required, but fails in two respects:

(a) The accuracy is limited to about 5 per cent, mainly on the score of reading accuracy.

(b) It is unsuitable for very low resistances (under a few ohms) or very high resistances (above about 50,000 ohms).

Special ohmmeters are sometimes employed for low value resistances. The best technique here is to shunt the unknown resistance across the meter, as shown in Fig. 11.1. The meter is first adjusted to full scale (I_1) by varying P (which should be at least 100 times the meter resistance R_m). The unknown resistance R is then shunted across the meter, causing the reading to drop to I_2. Then $R = R_m I_2/(I_1 - I_2)$. The meter may be calibrated in ohms or an existing meter may be used if R_m is known.

For high resistances the limitation is the very small current taken from the ordinary self-contained battery. If an external battery of 60 to 100 volts is used the range may be suitably extended and this technique is often used.

Megger Tests. High value resistances are often used in conditions such that the voltage across the resistor is several hundred. Moreover, a type of test often required is that of the insulation between certain portions of a circuit (as for instance between primary and secondary of a transformer). This may well be measured in hundreds of megohms and it is also essential to employ several hundred volts—the voltage being at least comparable with the working voltage which the instrument will have to withstand in operation.

For such tests a small portable h.t. generator is often used. This instrument, first marketed by Evershed and Vignoles under the trade name "Megger," comprises a small hand-driven magneto generator which develops a high voltage (usually 500, but sometimes as high as 2,000). A meter reads the current and is calibrated in megohms. The usual compensation against changing voltage is not employed, the meter being of the dynamometer type, having two coils, one connected as a voltage coil and the other as a current coil. The reading can then be made proportional to the two and will thus accurately read the true insulation resistance.

It may be noted that when using such an instrument to test a condenser the initial reading will be very low because of the rush of current charging the condenser. The apparent "resistance" rapidly rises, however, and a true value is obtained provided the handle is turned steadily so that the voltage is constant. Otherwise the reading will fluctuate all the time. In most Meggers a slipping clutch mechanism is provided so that if the handle is turned faster than required the generator only turns at a given speed and thus gives a constant output.

For special tests methods are adopted to meet the needs. Thus, for production testing a high voltage supply may be derived from the a.c. mains, using a step up transformer and a rectifier. The input is usually made variable so that the voltage may be brought up as required, and anything from 5,000 to 50,000 volts may be produced according to the tests required.

Leakage in such sets is not usually measured directly with a meter, since a breakdown of the insulation would cause a very large current which would wreck the meter. Some indirect method is usually employed, such as inserting a resistance of a few thousand ohms and reading the voltage across it with a valve voltmeter. In case of a breakdown the meter will not be seriously overloaded because the valve will limit. Moreover, the resistance itself will limit the current flowing even if the test sample breaks down completely and becomes a short circuit.

Bridge Methods. For accurate resistance testing a bridge is used. This is an arrangement, as shown in Fig. 11.2, having four resistances in the form of a closed square. A small d.c. voltage is applied across the corners AC and a galvanometer is connected across BD. Now the current from the battery will divide. That through ABC will be $V/(R_2+R_3)$, while through ADC we have $V/(R_1+R_4)$.

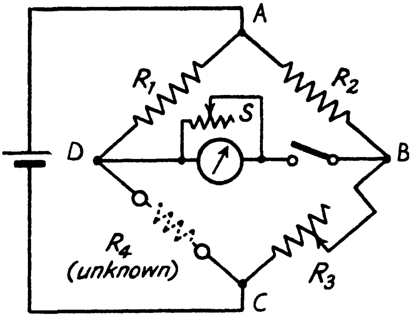


Fig. 11.2. Wheatstone Bridge for Resistance Measurement.

The voltage across $BC = \frac{R_3}{R_2+R_3} . V$

The voltage across $DC = \frac{R_4}{R_1+R_4} . V$

These will be equal if $R_3(R_1+R_4)=R_4(R_2+R_3)$

so that $R_1R_3+R_3R_4=R_2R_4+R_3R_4$

i.e. $R_1R_3=R_2R_4$

whence $R_4=\frac{R_1}{R_2}.R_3$

Now if R_4 is our unknown resistance and we make R_3 variable, we can adjust it so that this condition is complied with; under which condition there will be no difference of voltage between the points B and D. The galvanometer will thus not read and the bridge is said to be *balanced*.

R_1 and R_2 are called the *ratio arms*. If we make them equal, then $R_4=R_3$. By making $R_2=10R_1$ we shall balance when $R_3=10R_4$, and vice versa. Thus a resistance varying from 10 to 10,000 ohms can be used to measure from 1 to 100,000 ohms (or more if we make the ratio of R_1/R_2 greater).

This bridge principle is greatly used in measurement. R_3 must be a standard variable resistance, usually made up in a series of decades (e.g. 10 1-ohm steps, 10 of 10 ohms, and so on). Or it may be a calibrated rheostat, though the accuracy here is much worse.

The resistance S is to shunt the meter so that it will not be damaged when the bridge is off balance. It is desirable to use a sensitive centre-zero meter (giving full deflection with 50 microamps or less), but the current off balance may be many times as great as this. The meter, therefore, is shunted at first to avoid damage and a rough balance obtained. The shunt resistance may then be increased and finally removed when the bridge will be sensitive to very small changes.

It is also desirable to provide a switch or push button in the meter circuit as shown. This is to avoid damage to the meter from any surges of current which might occur due to the change of R_3 in the process of balancing. This is particularly liable to happen if one is measuring the resistance of a choke or other inductive circuit.

D.C. supply is essential unless the resistances (including the unknown) are non-inductive.

It is possible to balance the bridge by changing R_1 or R_2, thus obtaining a *variable-ratio bridge*. This technique is adopted for inductance and capacity bridges, as discussed later, because it is often easier to use a variable resistance than a variable inductance or capacity, but for resistance measurement the method offers no advantages. Sometimes R_1 and R_2 are replaced by a single potentiometer, the slider of which constitutes the point A. This gives a rapid change of ratio and a range of 1,000 : 1 is obtained on a single dial. The accuracy, however, is necessarily poor, which defeats the main reason for using a bridge.

Neon Tester. A form of tester which may be used for comparison purposes is that shown in Fig. 11.3. An ordinary neon lamp (such as an Osglim) is connected in series with a high resistance across a d.c. supply of 180 volts or more. The neon lamp will not conduct till the voltage reaches a certain value. When the circuit is switched on the condenser C charges, but the charge is delayed by the resistance R.

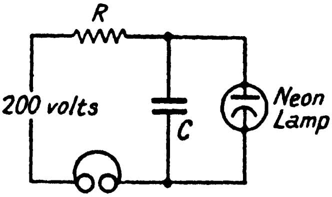


Fig. 11.3. Circuit of Neon Tester.

When the voltage reaches the critical voltage, however, the neon lamp becomes conducting and partially discharges the condenser. The process then recommences, the charge and discharge following one another in regular sequence. According to the choice of C and R the sequence may take 2 or 3 seconds or may occur many hundred times per second, in which case a musical note is heard in the telephones T.

If R is known and is replaced with a similar resistance the note will be the same. If the new resistance is higher in value the note will be lower in pitch and vice versa. To obtain a musical note the product of C in microfarads and R in megohms should be about ·001, but a musical note cannot be sustained with values of C much above 0·1μF. For large condensers and high resistances it is better to arrange the circuit to give slow discharges of 3 or 4 per second or less, so that the discharge frequency can be estimated by counting the "ticks."

CONDENSER TESTING

Measurement of Capacitance. It is often required to know the capacitance of a condenser, and here a variety of methods is available. One method depends upon tuning and employs an r.f. oscillator (or signal generator). Connect up the circuit as shown in Fig. 11.4. Various methods must now be adopted according to the circumstances. If one has a condenser of known capacitance, the first step is to connect this known condenser across the coil L and to tune in until the maximum signals are obtained in the telephones. Note the wavelength at which this occurs. Now replace the known condenser with the unknown capacitance and again repeat the performance.

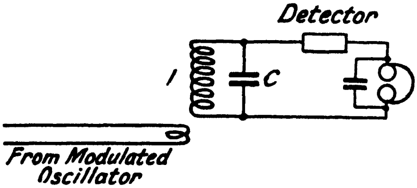


Fig. 11.4. Illustrating Use of Oscillator for Measuring Inductance or Capacitance.

The unknown capacitance is obtained from the expression:

$$C=\left(\frac{\lambda}{\lambda_1}\right)^2 C_1$$

where C_1=known capacitance;
λ_1=wavelength with known capacitance;
λ =wavelength with unknown capacitance.

The detector may be a crystal, a W.X.1 Westector or a diode, whichever is most convenient. Both C and C_1 should include the self-capacitance of the coil. The method thus becomes increasingly inaccurate for values of C less than about ·0001 μF. For best results C and C_1 should be similar.

If one has no condenser of which the value is known, or such that the rated valve may be assumed to be correct, it is necessary to obtain a coil having an inductance which is known within reasonable limits. A coil having 110 turns of 30 d.s.c. wire wound on a former 2-inch diameter will have an inductance of 500 μH approximately. Use this for the coil L in the circuit, and connect the unknown capacitance across it. Find the wavelength to which the combination is tuned, when the capacitance will be given approximately by the expression:

$$C=\frac{\lambda^2}{3{\cdot}55L}\times 10^{-6} \text{ microfarads}$$

where L=inductance in microhenries.
λ=wavelength in metres.

This method again is liable to inaccuracy due to coil capacitances, etc., if the capacitance to be measured is less than about ·0001 μF.

Neither method is suitable for capacitances exceeding about ·001 μF, owing to the fact that tuning becomes very flat with a large capacitance. For measurement of larger capacitances a bridge method is used.

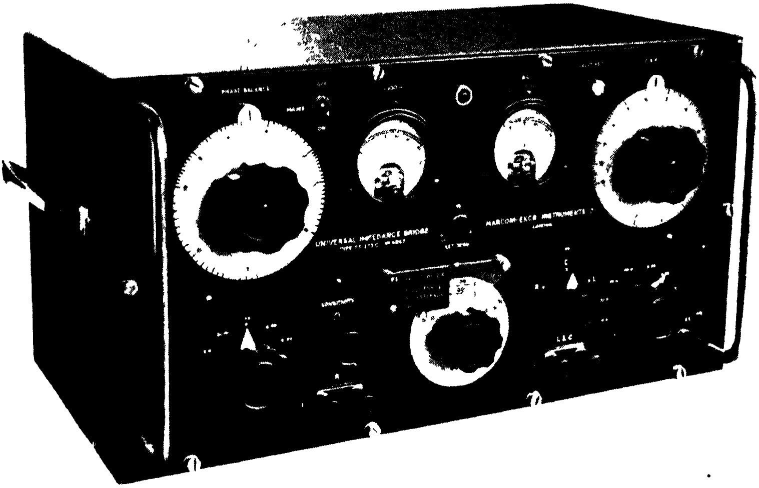
PLATE XIII

This Mullard Bridge is a very compact accessory for measuring the resistance or capacitance of components under a.c. conditions.

PLATE XIV

The Avo Valve Tester shown here gives rapid indication of the anode current, mutual conductance and other parameters of a valve. The top panel is taken up by a variety of different sockets so that any normal type of valve may be checked.

PLATE XV



The Marconi Impedance Bridge shown here is a valuable laboratory tool. It contains a 1000-c/s oscillator and measures capacitances and inductances over the full range encountered in normal radio practice. It also provides an indication of the Q of the coil when inductance measurements are being made.

In place of the detector and phones a valve voltmeter may be used, but this has the disadvantage of a relatively high self-capacitance. However, the total stray capacitance, including that of the voltmeter, may be determined by making a test first with no added capacitance. This will give the value of C_0 which must then be deducted from any subsequent values obtained with additional condensers across the circuit.

All the foregoing remarks apply to fixed condensers as well as variable condensers. A fault which is often found in fixed condensers, particularly of cheap manufacture, is that there is a complete break inside the condenser. The component, therefore, may appear correct on simple tests, but actually has no capacitance.

Bridge Methods. For laboratory testing a bridge arrangement is usually employed. This is illustrated in Fig. 11.5. There are four arms. The top two, called ratio arms, are fixed while the bottom two comprise the condenser under test and a standard calibrated variable condenser. The oscillator is switched on and the standard capacitance is varied until no sound is heard in the telephones. If $C_1 = C_2$, then $C_3 = C_4$.

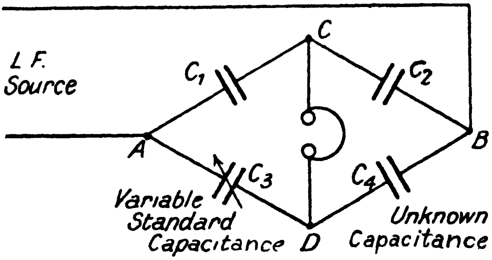


Fig. 11.5. Wien Bridge for Capacitance Measurement.

If no silent point is obtained the unknown condenser is either larger or smaller than the limits of the standard condenser and C_1 must be made unequal to C_2, so that C_3 may be unequal to C_4 in the same ratio. In such circumstances

$$C_4 = \frac{C_2}{C_1} \times C_3$$

It is also necessary for the losses in the condensers to be balanced. If they are not, the minimum is not sharp, but for rough tests this may be ignored. For further details see various works on Bridge Methods.[1]

If a calibrated variable condenser is not available the bridge of Fig. 11.6 may be used. This operates by varying the ratio arms, one of which is a fixed resistance and the other is a potentiometer used as a variable resistance. R_1 should be about 10,000 ohms. If R_2 is 10,000 ohms maximum and R is 1,000 ohms, the ratio of the bridge is variable from 1·1 to 1 down to 0·1 to 1.

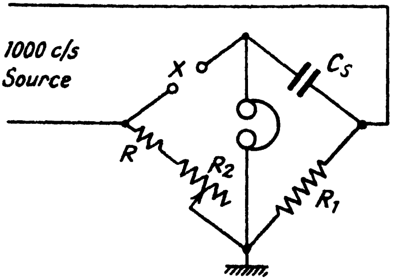


Fig. 11.6. Capacitance Bridge, Using Resistance Ratio Arms.

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[1] Notably W. H. Nottage, *Calculation and Measurement of Inductance and Capacity*; and B. Hague, *A.C. Bridge Methods*.

C_s is the standard condenser (fixed) and X is the unknown.

$$X = \frac{R_1}{R+R_2} \cdot C_s$$

Hence if $C_s = 100$ pF we can measure capacitances from 91 to 1,000 pF. If R_1 is changed to 1,000 ohms the range becomes 9·1 to 100 pF, while with $R_1 = 100{,}000$ ohms the range is 910 to 10,000 pF. In place of phones a magic eye may be used.

The "standard" condenser may be obtained specially calibrated from condenser makers or calibrated by the r.f. method previously quoted. A waxed silver mica type is best.

Condenser Loss. For a perfect balance the losses should be equalised. This may be done by connecting a small variable condenser of about 100 pF across R_1 and adjusting this simultaneously until a true null point is obtained.

The equivalent series resistance in the unknown condenser is then given by $R_x = C_1 R_2 / C_s$, C_1 being the capacitance (at balance) of the condenser connected across R_1. Both C_1 and R_2 will need to be adjusted one at a time, the zero becoming better and better until final balance is obtained. The power factor of the condenser is then $R_x C_1 \omega$.

For many purposes it is not necessary to know R_x, but it will be found useful to employ a phase balance by using this condenser C_1 as this sharpens the zero and increases the accuracy with which R_2 can be set.

Large Condensers. Simple bridge methods are suitable for condensers up to about ·01 μF. Beyond this value it is necessary to use special forms of bridge which are beyond the scope of this book, or to use an a.c. method. An alternating voltage is connected across the condenser, in series with an a.c. milliammeter, and the current flowing is noted. The capacitance is then given by

$$C = 159\, I / Vf \text{ microfarads.}$$

where V = applied voltage.
I = current in milliamps.
f = frequency of supply (cycles per sec.).

This method is useful for checking the value of paper condensers having capacitances of the order of microfarads, but it may be used, with sufficient voltage and a sensitive (a.c.) milliammeter, for quite small capacitances. There are on the market instruments of this class designed to operate from standard a.c. mains in which the meter is calibrated direct in capacitance, while a second scale shows resistance values, for obviously the same method may be used to measure resistance by the simple application of Ohm's Law.

Electrolytic Condensers. This method cannot be used for electrolytic condensers which are polarised and must only be allowed to pass current in one direction. For such condensers the circuit of

Fig. 11.7 is useful. The condenser is polarised by an amount just larger than the peak value of the a.c. (say twice the r.m.s. value for

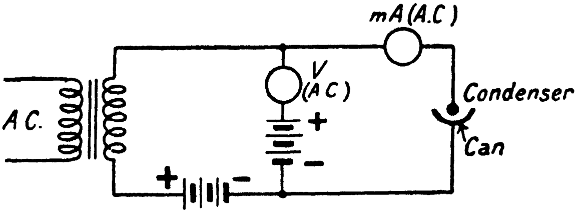

Fig. 11.7. Circuit for Testing Electrolytic Condensers.

safety), while an equal and opposite balancing voltage is applied in series with the voltmeter, which thus only responds to the a.c.

Condenser Matching. For matching the various sections of a gang condenser simple modifications of the methods so far outlined may be used. One convenient method is to adopt a wavemeter arrangement. The condenser under test is made to tune a coil coupled to a suitable local oscillator. The voltage developed operates a valve voltmeter, and the capacitance of the condenser is adjusted to give maximum reading. The coil is then connected to the next condenser in the gang, when the same reading on the valve voltmeter should be obtained. If not, the second condenser is suitably adjusted. Alternatively, each section may be matched against a standard by a similar process.

Another method is to connect the condensers to be matched to two oscillating circuits. If the capacitances are equal and the remainder of the circuit has previously been matched up, there will be no beat note between the oscillations, but if the condensers are out of gang a beat will be heard which will be higher in pitch the greater the discrepancy. The condensers can then be individually adjusted to reduce the beat note to zero.

Insulation. A further test often required on paper condensers is that of their insulation. The only reliable test for this is to make some form of charge-holding test. If a battery of, say, 100 volts is connected across the condenser, it will become charged. If the battery is now removed the condenser will remain charged, and if it is a good condenser, and the insulation is up to standard, this charge should be maintained for at least five minutes, and much longer in the case of a really high-class condenser. If, on the other hand, there is a leakage on the condenser, either internally or due to surface leakage between the terminals, the charge will leak away very rapidly.

As a rough test the terminals of the condenser may be short circuited, causing it to discharge with a sharp spark. If it is now charged again and left for five minutes it may again be discharged in the same way. If the spark is still as sharp as before the insulation is satisfactory. The test cannot be made on electrolytic condensers, which have a permanent leak as already explained.

A more scientific test can be made with a meter. The test really requires a ballistic galvanometer, but a high-resistance voltmeter, can be used satisfactorily. Connect a battery of 100 to 200 volts across the condenser, and then, having removed the battery, connect the high-resistance voltmeter across the condenser. This must be done quickly, and with one eye on the voltmeter reading. The needle will flick over to a certain value, and then will gradually discharge, falling away more or less rapidly, depending upon the capacitance of the condenser and the resistance of the voltmeter. The maximum reading to which the needle mounts before it commences to fall back again should be noted.

The condenser should now be charged again from the battery, in the same direction as before, and left to stand for five minutes. At the end of this period the voltmeter should again be connected across the condenser and the maximum reading on the voltmeter noted. If there has been no loss of charge due to leakage in the intervening five minutes, the voltmeter reading will be much the same as before, within the limits of observational error. A marked discrepancy indicates that the condenser has a leakage of some sort across it, while if there is no reading at all, the condenser has lost all its charge and there is a serious leakage.

COIL TESTS

Inductance Measurement. The inductance of a coil may also be determined by the use of an oscillator. Connect across the coil a capacitance of anything from ·0003 μF to ·0005 μF, the circuit being arranged in the same way as in Fig. 11.4. Tune the oscillator to give the maximum signal in the phones (or valve voltmeter). Having found the wave-length to which the combination tunes, the inductance may be obtained from the expression:

$$L = \frac{\lambda^2}{3{\cdot}55C} \times 10^{-6} \text{ microhenries}$$

where C = capacitance in microfarads.
λ = wavelength in metres.

If one does not know the value of the condenser which is being used to tune the circuit, a standard inductance may be used, the circuit being tuned with the same condenser first with the unknown inductance and then with the standard inductance. Knowing the wave-length in the two cases, the value of the unknown inductance can be determined from the expression:

$$L = \left(\frac{\lambda}{\lambda_1}\right)^2 L_1$$

where L_1 = known inductance.
λ_1 = wave-length with known inductance.
λ = wave-length with unknown inductance.

Mutual Inductance. The mutual inductance between two coils can be estimated in the following way: Connect the coils in series and measure the total inductance. Now reverse the connections to one of the coils, so that the coupling between the coils is reversed, and again measure the inductance.

The difference between the two readings, divided by four, gives the mutual inductance between the coils.

In one case $L=L_1+L_2+2M$, and in the other $L=L_1+L_2-2M$. The difference between the readings is thus $4M$.

Bridge Methods. A bridge for measuring inductance is more convenient for laboratory work. Such a bridge is shown in Fig. 11.8. Here the two ratio arms are again resistances, one fixed and one variable. L_s is the standard coil and X the unknown, which is given by

$$L_x = \frac{R_1}{R+R_2} L_s$$

As with the capacitance bridge, different values of R_1 may be used to change the range.

In this case, however, we not only have to balance the inductances, but also the resistances of the circuits, and therefore a variable resistance is shown included in the circuit. We cannot say offhand in which arm this resistance must be placed. We may find that the resistance of the standard is more or less than that of the unknown inductance, and accordingly we must place the extra resistance in either the right hand or the left hand arm respectively in order to balance for resistance.

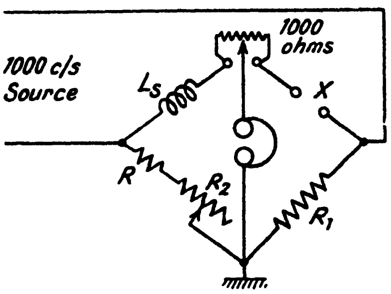

Fig. 11.8. Inductance Bridge.

With the circuit shown a potentiometer is used. The movement of the slider of the potentiometer takes resistance out of one arm and puts it in the other, an arrangement which obviates any need for switching.

In practice one has to balance this bridge by adjusting both the inductance and the resistance simultaneously, obtaining a minimum on one, then reducing the strength of this minimum on the other. Going from one to the other in this way a silent point is ultimately obtained, and this gives the inductance of the unknown coil.

The standard inductance may be made in the form of a single layer coil and the inductance calculated from the expression

$$L = \frac{0{\cdot}2\,N^2D^2}{3{\cdot}5\,D+8l}\ \mu H$$

where D is the diameter in inches.
l is the length in inches.
N is the number of turns.

Care must be taken to avoid coupling between the standard and the coil under test.

Owen Bridge. Standard inductances are not so easy to arrange as condensers, and there is always the danger of coupling between the coil under test and the standard. Hence, a bridge using a standard condenser as the basis of comparison may be more convenient. There are several such bridges available, one of the most practicable being the Owen bridge, shown in Fig. 11.9.

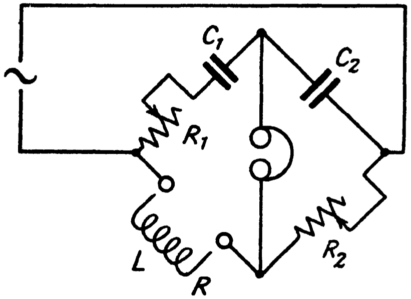

Fig. 11.9. Owen Bridge for Inductance Measurement.

Here C_1 and C_2 are fixed condensers, preferably equal and about 0·25 μF each. Paper tubular condensers can be used. R_1 and R_2 have both to be adjusted simultaneously, the balance condition being obtained when

$L = R_1 R_2 C_2.$

$R = R_2 C_2 / C_1$ (R being the resistance of the coil).

If R_2 is made the phase balance, and thus of the same order R_4, about 200 ohms maximum, R_1 can be used as the inductance balance, and calibrated accordingly. A convenient value for R_1 is 5,000 ohms max., and if C_2 is provided in two values of 0·25 and ·025 μF respectively, the bridge can be used to cover a range of 20 μH to 0·1 H.

The accurate knowledge of R is useful in that it determines the Q of the coil ($= L\omega / R$). The value is not given directly and the bridge is a little awkward to get used to owing to the need for adjusting R_1 and R_2 together, since *both* must be right before a sharp balance is obtained. The bridge, however, has the merit of being independent of frequency.

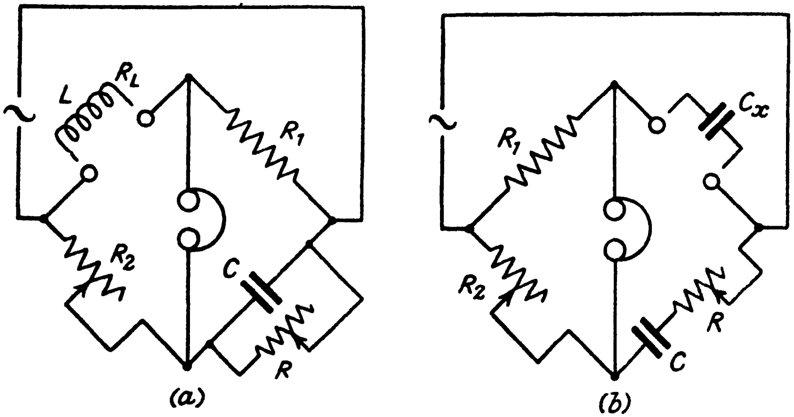

Fig. 11.10. Universal Bridge.

Universal Bridge. Another bridge is shown in Fig. 11.10 (*a*). This is a circuit in which the inductance is balanced by a capacitance in the opposite arm. It is still necessary to adjust the phase for true balance, but the interaction of the controls is not so marked and the adjustment is easier. Also, the phase control R can be calibrated directly in Q and since C is not changed (different ratios being obtained by altering R_1), this calibration holds over the whole range.

Balance is obtained when $L=CR_1R_2$ and $R=R_1R_2/R_L$.

This bridge has the further advantage that by a slight rearrangement the same components can provide a capacitance bridge. R_1 is changed to the opposite arm and R is placed in series with C, as shown in Fig. 11.10 (*b*).

Coil Matching. Matching of inductances is best carried out by a valve-voltmeter method similar to that suggested for condenser matching. In this case the coil should be tuned to a suitable local oscillation with a condenser marked with limits within which the coil can be accepted. Within limits the inductance may be adjusted by varying the spacing of the end turns. Outside these limits the coil is either rejected or put on one side for modification by adding or stripping turns.

Iron-Cored Inductances. Measurement of large inductances, particularly iron-cored inductances, is a matter of considerable interest in radio work. Here the measurement is one of a little difficulty, for one has to take account of the presence of steady current flowing through the winding.

The effective permeability of the iron, which is what determines the inductance under practical conditions, falls off steadily and somewhat rapidly as we increase the steady magnetisation of the iron, so that the larger the steady current the less the inductance of the coil. This effect is known as "saturation."

A further effect is that the inductance of an iron-cored coil varies considerably with the alternating component of the current flowing through it. We have two essentials, therefore, to comply with in making our measurement.

1. The steady current flowing through the winding must be commensurate with the value to be used in practice.
2. The alternating component of the current must also be of the correct order.

In practice a value of 1 milliamp a.c. will be found suitable for transformers and high-inductance chokes, as the difference between the inductance under such conditions and that with small currents flowing is negligible. With smoothing chokes values of 10 to 50 milliamperes should be used.

A circuit which can be employed in making these measurements is that shown in Fig. 11.11. In series with the inductance to be measured is a small resistance. This should be of such a value that it is negligible in comparison with the impedance of the inductance to be measured. A value of 1,000 ohms is suitable for inductances of 50 henries or more. This will give an a.c. voltage of 1 volt. Below this, the resistance should be reduced and the a.c. component increased—e.g. 100 ohms and 10 mA a.c. Across this resistance is connected a valve voltmeter. The circuit is completed with a switch having two positions. In the first, the circuit contains an a.c. milliammeter capable of reading the a.c. component to be used. In the second a d.c. milliammeter and battery is brought into use, the sizes depending on the polarising current required.

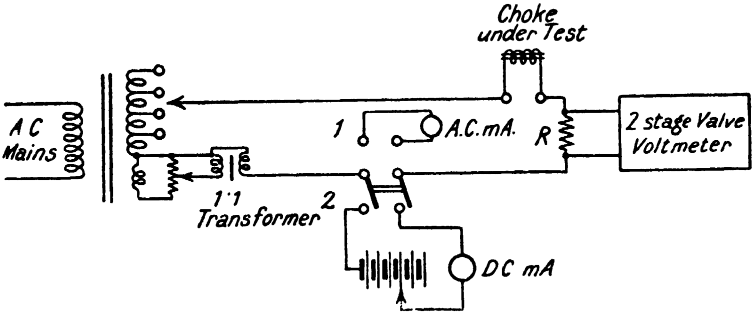

Fig. 11.11. Circuit for Testing Iron-Cored Inductances.

A variable transformer is employed connecting the circuit to the mains supply. The voltage is increased (with the switch in position 1) until the required current (1 or 10 milliamperes, as the case may be) is flowing in the circuit. The voltage drop on the resistance *R* will cause a deflection on the valve voltmeter, and this deflection must be noted. Throughout the measurements we then know this deflection on the valve voltmeter corresponds to a definite value of a.c.

The switch is now thrown into position 2, which brings in the battery and a d.c. ammeter. This is now adjusted until the requisite direct current passes through the choke. This will have no effect upon the valve voltmeter, which does not take any account of d.c. voltages applied across its terminals. The voltmeter should be disconnected, however, while adjusting the d.c. or the large voltages set up due to sudden change of the current in the choke may damage the meter. The a.c. voltage applied to the circuit is now varied until the reading on the valve voltmeter is the same as before, indicating that the required value of alternating current is flowing. The voltage across the circuit is measured with a suitable a.c. voltmeter (not shown in the circuit), and by dividing this voltage by the pre-determined value of alternating current to which the circuit has been adjusted, we are able to determine the impedance of the choke.

In nearly all cases this impedance may be taken to be purely reactive since the resistance is usually negligible. Such being the case, one may assume that:

$$\text{Inductance} = \frac{\text{A.C. voltage across choke}}{6{\cdot}28 \times \text{frequency} \times \text{a.c. amperes.}}$$

The method is one which gives good practical results with an accuracy quite sufficient for normal purposes. The 1 : 1 transformer in the figure is to obviate errors due to the varying resistance of the potentiometer. Otherwise the d.c. flowing through this will affect the reading on the a.c. voltmeter across the supply.

Alternative methods of obtaining a variable supply voltage can obviously be used. Thus a continuously variable transformer, such as a Variac, may be employed or the primary of the transformer may be fed from a heavy duty potentiometer across the mains.

If the calibration of the valve voltmeter is accurate, the a.c. milliammeter may be dispensed with. Knowing the resistance *R* and the voltage across it the a.c. current may be readily calculated.

The R.C.M.F. has adopted an alternative standard, the inductance being measured with 3·5 volts a.c. across the choke. For this to be done it is necessary to calibrate the valve voltmeter in terms of the a.c. flowing. Otherwise the method remains unaltered.

Short-Circuit Tests. Short circuits on a tuning coil are best detected by an inductance measurement. The short-circuited turns cause a reduction in the inductance which is considerable if the short circuit is at all serious. A still more definite test is an r.f. magnification test, as is described later. The extra damping due to the short-circuited turns will show up at once.

Short circuits in a multi-turn coil such as a transformer bobbin are best shown up by using an l.f. oscillator having air-cored coils. A simple Hartley circuit is sufficient, the tuning condenser being adjusted to give a note of about 1,000 cycles. The h.t. voltage should be adjusted so that the oscillation is not too strong. The suspected coil is brought close to the oscillator coil. If it is O.K. nothing will happen, but if there are short-circuited turns in the winding the note from the oscillator will alter in pitch or strength or both.

Elaborations of this method may be made so sensitive that a single short-circuited turn can be detected.

For detecting short circuits on mains transformers it is convenient to use a 500-cycle supply instead of the usual 50 cycles. The energy circulating in the short-circuited turns is then increased 100-fold and the winding will rapidly heat up.

In production testing it is not necessary to wait for the winding to heat up. If an a.c. milliammeter is placed in the primary circuit the energy absorbed in the short-circuited turns will show up by an increased primary current. The meter must have a large factor of safety or it may burn out on a bad short circuit, particularly when switching on.

TRANSFORMER TESTS

The only test which one need make in ordinary practice on low-frequency transformers is that for broken windings, or a short circuit to the core. One may find that one of the two windings is broken or incorrectly connected. Occasionally a check on inductance may be desirable, but in the main the faults encountered are either simple or beyond the scope of this work.

Ratio Tests. In the production of transformers more elaborate tests are naturally required. The bobbins are usually tested for short circuits, before being assembled, by one of the methods already described.

The transformer is then tested for ratio at whatever frequencies may be considered desirable. Usually two frequencies are chosen, one in the region of 100 cycles sec. and the other around 4,000/8,000 cycles sec., depending on the response of the transformer.

The method is to connect the transformer in a circuit either containing or representing a valve, to introduce a constant voltage across the input (grid) circuit, and to note the voltage developed across the secondary of the transformer, this being measured by a valve voltmeter or similar device. The conditions must duplicate practical working as far as possible and suitable tolerances are then fixed, outside which the component is rejected.

Tests for insulation resistance are also more severe in production, usually being carried out at several hundred volts a.c.

Mains Transformers. Tests on mains transformers are principally a matter of testing the insulation between windings and to core either with a Megger or, in production, with 1,000 to 2,000 volts a.c. A lamp in series with the primary of the step-up transformer will act as a protection in the event of a breakdown.

Tests on the voltages on the secondary are carried out quite simply with an a.c. voltmeter, the winding in question having connected across it a load equivalent to the normal load. In this connection it is worth remembering that the r.m.s. current supplied by a rectifier transformer is greater than the d.c. load after rectifying due to the peaky waveform. The ratio of a.c. to d.c. ranges from 1·5 to 3·0, depending on the type of rectifier, the size of the reservoir condenser and the relative current.

The no-load (magnetising) current should also be checked. This should not exceed about 25 per cent of the full load current. If this is excessive it indicates insufficient iron in the magnetic circuit or else short-circuited turns. In any case the meter should have a full scale deflection of twice the full load current to avoid burn-outs due to sudden surges.

VALVE TESTS

The obvious test to be made on a valve is that of taking its characteristics. This, of course, is a cumbersome business, but in some instances one does require to know something about the parameters of the valve. It will not be out of place, therefore, to give details of how this may be done. The circuit should be arranged as shown in Fig. 11.12. There is a voltmeter to read the anode voltage, a milliammeter to determine the anode current and a voltmeter to determine the grid voltage. The high-tension voltage must be variable in steps, and the tappings on an ordinary h.t. battery will serve for this purpose. The grid voltage must also be variable in steps and for ordinary purposes it is sufficient to use the 1½-volt tap on a grid bias battery. In special cases a potentiometer is required across all or part of the circuit so that finer variations are possible, and in the figure a potentiometer is shown across the filament battery for this purpose.

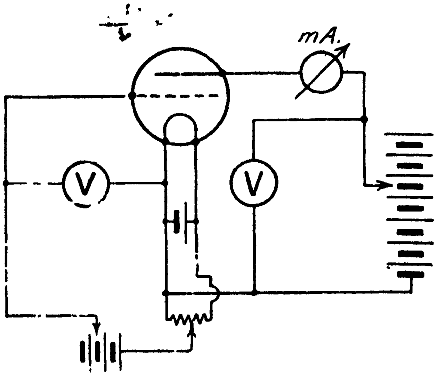

Fig. 11.12. Circuit for taking Valve Characteristics.

In order to determine the characteristics a normal anode voltage is usually used, and the grid bias is varied from zero to some negative value until the anode current has been reduced practically to zero. The test is then repeated for one or two other values of anode voltage. If a screen-grid valve is being used, the screen must be connected to the correct voltage during the test, and the same remark applies to pentode valves.

If other characteristics are required, these must be plotted by varying the required voltages. For example, with power valves, one often requires to know the variation of current with anode voltage at a fixed value of grid voltage. Any such characteristic may easily be taken with the apparatus shown.

Usually, however, it is sufficient to determine the internal resistance and amplification factor under working conditions. For this purpose the valve should be set up with its correct anode voltage and grid bias. First of all the anode voltage is increased to, say 10 volts above the normal value and the anode current noted. The anode voltage is then reduced to 10 volts below normal value, and the current again noted. This gives us the first parameter.

$$\text{Internal resistance} = \frac{\text{Change in anode voltage (20 in this case)}}{\text{Change in anode current.}}$$

The anode voltage is now restored to its normal value, and the grid voltage is increased to 1½ volts above normal, and the anode current noted. The grid voltage is now reduced to 1½ volts below normal, and the anode current again noted. This gives us the second parameter. The h.t. should be disconnected while changing over the grid bias to avoid the possibility of a dangerously large anode current.

$$\text{Mutual conductance} = \frac{\text{Change in anode current}}{\text{Change in grid voltage (3 in this case).}}$$

The amplification factor is obtained by multiplying these two factors together.

Where one is dealing with a.c. valves all measurements must, of course, be made relative to the cathode, while the heater is supplied separately with current either from a 4-volt transformer or a 4-volt battery as required. This requires the use of a special holder and a slight modification of the connections.

Valve Testers. The multiplicity of modern valves has led to the introduction of various forms of valve tester. These are, in the main, an arrangement of valve-holders to suit differing types, together with a supply of d.c. for the anode and a.c. for the heater. Often they are only concerned to measure the "emission"—actually the anode current with zero grid volts and 100 volts h.t. This is only a partial test on the performance of the valve.

Wherever possible a valve tester should be of such a type that the value of *g*, at least, can be determined. The provision of many different sockets is an asset, but the engineer should not be content with so-called emission tests.

When testing multi-electrode valves it is essential to hold the screen voltage steady. If the screen supply is obtained from the same source as the anode supply interaction between the two may cause the screen voltage to vary. A screen voltage meter should be provided and the voltage adjusted to the correct value on each reading.

Detailed discussion of the various forms of valve tester on the market is neither necessary or desirable. If the tester will perform the simple tests just outlined it will be satisfactory.

MISCELLANEOUS TESTS

Measuring R.F. Resistances. The measurement of r.f. resistance and r.f. loss is a matter of considerable difficulty owing to the number of factors which can cause trouble. The use of valve voltmeters is not satisfactory for this class of work, and the best method is by the use of thermo-couples of the type just described to measure the actual current in the circuit in conjunction with what is known as the resistance-variation method. Fig. 11.13 shows a simple circuit. Current is passed through a resistance in series with which is a thermo-couple for measuring the current. Provided that the current through this resistance is kept constant the voltage across the whole circuit must remain the same, and this is the first and fundamental requirement for any high-frequency measurements. It is desirable to supply the energy from an oscillator capable of generating a current of several hundred milliamps, so that our requirements, which will not usually exceed a few milliamps, will be well within the capacity of the oscillator.

Across this source of voltage is connected the circuit under test. This may consist of a coil tuned with a standard low-loss condenser and provision must be made in this circuit for introducing suitable resistances. A second thermo-couple is included to measure the current in this branch of the circuit.

The current is first measured with no added resistance. A small series resistance is then inserted at the point marked, and the current is again measured, precautions having been taken to ensure that the current through the first thermo-couple is the same as before, so that the voltage across the circuit remains unaltered. In general this will require a small readjustment to the oscillator, as the power absorbed is now slightly less than before, due to the extra resistance in circuit. We are now enabled to determine the resistance of the tuned circuit from the following relation:

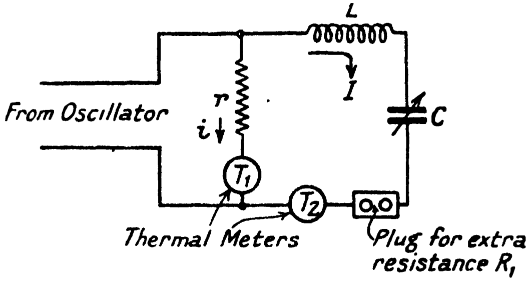

Fig 11.13. Circuit for Measuring R.F. Resistance.

$$E = I_1 R = I_2 (R + R_1) \text{ where } R = \text{r.f. resistance of circuit}$$
$$R_1 = \text{added resistance.}$$

We know I_1, I_2 and R_1 so that we can find R.

E, of course, is equal to ir, where r includes the heater resistance of the thermo-couple T_1 in series, but we do not require to evaluate this. It is sufficient to keep the current i constant.

Layout. In practice this operation is carried out several times with different resistances, and the r.f. resistance is taken as the mean of the various readings obtained. It is, in point of fact, preferable to obtain the results graphically by plotting the reciprocal of the current against the added resistance in the manner shown in Fig. 11.14. All the points so obtained should lie on a straight line which when produced to cut the resistance axis will give the effective resistance of the circuit.

If the points do not lie on a straight line it indicates that some source of error is being introduced. Either the voltage in the circuit is not remaining constant or additional voltage is being induced in the circuit due to stray coupling. This latter form of trouble is particularly prevalent and it is necessary to use leads as short as possible and to run them not more than half an inch away from one another, so that there is no closed loop formed which could pick up voltage by stray induction. The oscillator should be screened and located several feet away.

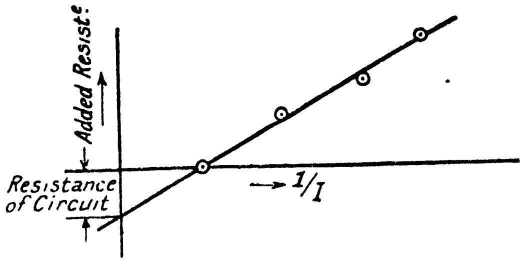

Fig. 11.14. Graphical Method of Arriving at Resistance.

It is also essential that the layout of the circuit shall remain exactly the same throughout the experiments. For this purpose the resistance inserted in the circuit is best made up in the form of a small plug-in unit, which always plugs into the same position and occupies the same space. The use of any form of resistance box is not practicable because the configuration of the circuit in passing through the different resistances is not the same for each test, and this is quite easily able to invalidate the results. The actual construction of the resistances is detailed shortly.

Resistance of Leads. The resistance so obtained includes the resistance of the thermo-couple T_2, and the resistance of the leads and variable condenser. For any accurate measurements these must all be evaluated. The resistance of the thermo-couple may be taken as the same as its d.c. resistance, provided it is of the vacuo-junction type which uses very fine wire for the heater. The resistance of the leads is generally a small fraction of an ohm, as also is the resistance of the condenser if this is of good quality, and these two may be neglected for ordinary measurements.

The resistance of the leads, however, may be evaluated if desired by connecting all the leads together to form a complete circuit, so that we have across our source of voltage the various leads in series with the resistance and the thermo-couple, omitting the coil and condenser. These leads must be run very close together in order to minimise inductance, because at a frequency of 1,000 kilocycles an inductance of as little as a quarter of a microhenry has an impedance over an ohm,[1] and the apparent resistance will be increased accordingly.

The resistance of the circuit is then obtained by the resistance-variation method just described, and from this resistance that of the thermo-couple heater must be deducted. The remaining resistance is that of the leads.

Resistances. The resistance must be constructed of fine-gauge eureka wire. If the wire is sufficiently thin the skin effect is not appreciable, and the resistance of the wire at high frequencies is practically the same as that to direct current. The resistances should be made up in short straight lengths as far as possible. If this is not practicable, then the resistance must be wound round a small (cylindrical) former in a non-inductive fashion. The best way to do this is to wind one half of the wire in one direction and the other half in the opposite direction, keeping the various turns on the former a distance apart equal to at least five times the diameter of the wire, otherwise the high-frequency resistance increases, due to interaction.

Generally speaking, it will be found that high-frequency measurements require considerable time to set up in order to eliminate the various minor troubles of this sort which arise. Once the apparatus is correctly set up, however, it will usually be found to give consistent and reliable results.

TABLE VII

MAXIMUM DIAMETER OF WIRE (INS.) IF R.F. RESISTANCE IS NOT TO EXCEED D.C. RESISTANCE BY MORE THAN 1 PER CENT

Wave-length (metres)	3,000	1,500	500	300	150	30
Copper . .	·014	·0099	·0057	·0044	·0031	—
Eureka . .	·075	·053	·030	·024	·016	·0047

The table herewith shows the gauge of wire which may safely be used under various conditions. The figures apply to straight isolated wires. If the wire is doubled back on its tracks or wound round a former the skin effect is increased and it is better to use a smaller gauge. The high-frequency resistance for the dummy aerial circuit described in Chapter X must be constructed in the manner just described, so that its resistance under working condition may be the same as the value measured with direct current.

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[1] This impedance will be in quadrature with the resistance, and since the total circuit resistance includes the heater of the thermo-couple, it will be of the order of 3 ohms. 1 ohm in quadrature with this will give an impedance of 3.3 ohms—an increase of 10 per cent.

Measurement of Q. In recent years the direct measurement of r.f. resistance has largely given way to a check on the Q of the coil, or circuit. For this purpose a small series resistance is included in the earthy end of the circuit, as shown in Fig. 11.15, and a known current is passed through this resistance. If the resistance is 0·05 ohm and the current is 20 mA the voltage injected into the circuit is 1 mV. The voltage across the circuit is then measured with a valve voltmeter, when the ratio of the output voltage to the input voltage is the Q of the circuit. Thus a circuit with a Q of 200 would develop 0·2 volt.

The method has the disadvantage that if R is to be negligibly small the current through it must be large if the output is to be reasonable (and 0·1 to 0·2 volt is too small to be read conveniently on a normal valve voltmeter). But this requires a fairly powerful oscillator which then has to be very carefully screened to avoid direct pick-up. Clearly, if any voltage is induced other than by means of the injection resistance the output voltage will be too high, giving optimistic readings of Q. This is a very real difficulty particularly above 1 Mc/s.

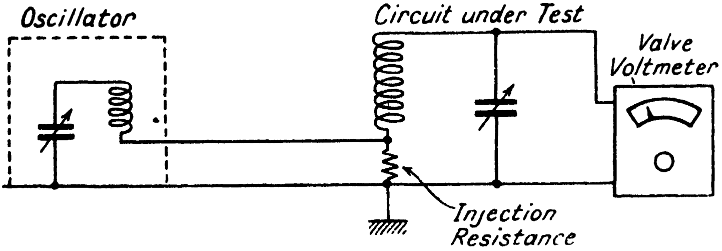


Fig. 11.15. Layout of Q Meter.

An alternative method is to inject the voltage by some other form of coupling such as an inductive coupling or a small capacitance connected to the "live" end of the circuit under test. The reading of the valve voltmeter is then adjusted to a convenient value, say 1 volt, and the circuit mistuned by a given amount, when the reading of the valve voltmeter will fall.

The mis-tuning may be effected by altering either the oscillator frequency or the tuning capacitance. In the former case we alter the frequency on each side of resonance until the voltmeter indicates 0·71 times the voltage at resonance. Then if δf is the total frequency swing (i.e. $f_1 - f_2$ where f_1 and f_2 are the two frequencies which give $V = 0{\cdot}71\ V_0$) and f_0 is the resonant frequency, Q is given by the simple expression $Q = f_0/\delta f$.

If the mis-tuning is carried out by altering the capacitance, then if C_0 is the normal tuning capacitance at resonance and δC is the total capacitance swing between the two values of C which reduce the voltage to 0·71 V_0, Q is given by $2C_0/\delta C$, very nearly.

This method has the advantage that the method by which the energy is picked up by the circuit is immaterial (so that it may include stray radiation) provided it is the same in the two conditions, which is a valid assumption as long as the coupling to the oscillator is only small.

For measuring coils a high-grade condenser is used, of which the loss is either known or assumed to be negligible. This condenser is usually calibrated in pF for convenience (a refinement essential if the second method is to be adopted).

CHAPTER XII

THE CATHODE RAY OSCILLOGRAPH

WITHIN the last few years the cathode ray tube has become used to an increasing extent in radio technique, and it is therefore, desirable to give a brief description of the tube and indicate some of the methods of use.

The cathode ray tube is an arrangement somewhat similar to an ordinary valve in its basic action. It contains a cathode emitting electrons and in proximity thereto an anode in the form of a disc with hole in the centre. Electrons are attracted from the cathode by the application of a positive potential to the anode, but the electrons which reach the region in the centre of the disc, shoot through the hole and continue in their transit in a straight line until they reach the walls of the bulb in which the assembly is housed. This bulb is made in the form of a long tube on the end of which is a coating of fluorescent material which has the property of glowing under the impact of electrons. Thus, although the beam of electrons is itself invisible, its presence is denoted by a small spot of light where the electrons strike the fluorescent screen.

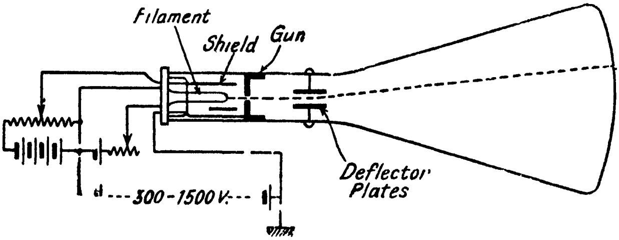


Fig. 12.1. Diagram of Soft Cathode-Ray Oscillograph.

It is necessary to include focusing arrangements so that the electron pencil projected from the anode may be concentrated, causing the electrons to focus into a very compact bundle just at the point where they strike the screen, giving a small clearly defined spot. The focusing is arranged in two main ways. In the simpler types of tube a shield or cylinder is placed around the cathode and a suitable, usually negative, potential is placed on this shield which prevents the electrons from diverging as they leave the cathode, and tends to concentrate them in a narrow pencil. The composite electric field produced by this shield and the anode or gun, results in a fairly concentrated jet of electrons, and it will be clear that the action of the shield is an advantage, in that it tends to drive the majority of the electrons through the hole in the gun instead of allowing the greater portion to be wasted.

This action in itself is not sufficient and the tube, therefore, is filled with a small quantity of inert gas such as argon. The electrons in their travel down the tube encounter molecules of this gas which they ionise, knocking off electrons by collision and leaving positively charged ions. These themselves are attracted to the electron beam and being relatively heavy they stay in the beam and in turn attract the electrons themselves so that they act as a concentrating force within the beam itself, and this method of focusing is very effective.

Gas focusing has two main disadvantages. Owing to the relative mass of the ions they are unable to stay in the beam at high deflection speeds. (The exact significance of this will be appreciated shortly.) Secondly, some of the ions find their way back to the cathode which they bombard and ultimately destroy, so that the life of the tube is limited.

The alternative type of tube uses a nard vacuum as in the modern valve, and obtains the necessary focusing action by the use of two or more anodes arranged one after the other at increasing potentials. By correct choice of these potentials in association with the voltage on the shield, an electric field is produced of such a form that it causes the electrons leaving the last gun to converge into a focus at the screen.

The hard tube is less sensitive but has a longer life owing to the absence of ionic bombardment. There are certain difficulties which occur with large deflections, but these can be overcome and need not be discussed here.

Deflection of Beam. Now this electron pencil can be caused to deviate from its straight line by the application of electric or magnetic fields. The usual deflection is electrostatic, obtained by placing two deflector plates, one on either side of the beam. The application of a voltage across these plates produces an electric field which deflects the beam, and therefore causes the spot on the screen to move. By using two pairs of deflector plates, one at right-angles to the other, the spot can be moved in two directions at right-angles, and therefore can be made to plot waveforms and curves of various types.

If two coils are placed on each side of the tube (external to the tube) and current passed through the coils, the magnetic field produced will also deflect the beam, in a direction at right-angles to the line passing through the centre of the coils. This magnetic deflection is sometimes useful, although the fact that power is consumed by the passage of current through the coils is a disadvantage. With the electrostatic type of deflection, of course, the power consumed is negligible. The possibility of magnetic deflection must be borne in mind for stray magnetic fields (e.g. from transformers) in the vicinity of the tube will cause the spot to be deflected, and this may introduce disturbances on the waveform or other trace being examined. All magnetic influences, therefore, should be kept well away from the tube as far as possible, or else the tube itself should be housed in a sheath of mu-metal or similar material of high magnetic permeability.

Time Bases. The simplest application of the tube is the examination of the actual waveform of the current or voltage. The voltage to be examined is applied across the vertical deflector plates and causes the spot to oscillate up and down and thereby elongate itself into a line. If at the same time the spot can be given a uniform movement in the horizontal direction, the movement of the spot will trace out the actual waveform of the voltage. Since the voltages with which we deal in practice recur many hundreds or even thousands of times per second, it is necessary for the trace of the spot to repeat itself over and over again. This is achieved by what is called a *time base*, which in its simplest form consists of a condenser charged through a high resistance. The voltage on the condenser does not build up instantly to its full value, but acquires its voltage gradually, so that if the horizontal deflector plates are connected across the condenser, the gradually increasing voltage will cause the spot to move relatively slowly across the screen.

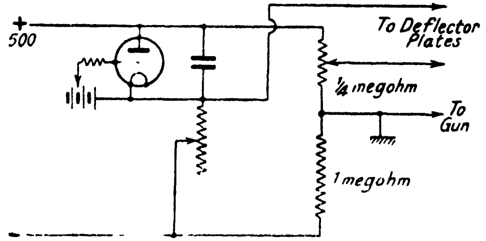


Fig. 12.2. Simple Time-Base Circuit.

When it has reached the full extent of its travel, the condenser is discharged by a form of valve known as a gas discharge relay. This is an arrangement similar to an ordinary triode. It contains cathode, grid and anode, but it is filled with a small quantity of gas such as neon or mercury vapour. If a small negative voltage is placed on the grid of the tube it will not conduct until the anode voltage reaches a certain critical value. The valve is connected across the condenser; when the voltage on the condenser reaches the critical value, the tube conducts, the condenser is discharged and the whole operation recommences.

This cycle of operation can be made to repeat itself at any desired speed from once every few seconds up to several hundred thousand times per second, and every time the action occurs, the spot on the cathode ray screen will move at a uniform rate across the screen, and then, when the discharge occurs, it will fly back and recommence.

If, therefore, the time of travel across the screen can be arranged to correspond to two or three complete waveforms of the voltage to be examined, we shall get a trace on the screen showing two or three distinct cycles. It is possible, by comparatively simple arrangement, to synchronise the time base with the voltage under test or the "work" voltage as it is called, so that the spot traces over exactly the same path each time, with the result that a more or less steady pattern appears to the eye although the actual tracing is taking place, perhaps, many thousands of times per second.

Waveform Analysis. The application of the device in this simple form is obvious. It enables one to see at once whether any distortion is taking place in, say, a low-frequency amplifier. One can examine the input waveform and make sure that it is reasonably sinusoidal in shape and does not contain any serious harmonics. The point of examination can then be transferred to successively later stages in the amplifier. At every point the waveform should be still of the same pure character.

The amplitude will, of course, increase due to the amplification in the equipment under test, therefore it will be necessary to step down the voltage suitably to an increasing extent. This reduction in voltage may easily be obtained by a potentiometer arrangement, as in Fig. 12.3. The resistance of the potentiometer can be several megohms without affecting the operation because the input impedance of the deflector plates to the cathode ray tube is simply that due to the capacitance between the plates which is only a matter of 10–20 micro-microfarads, which behaves at ordinary frequencies as an infinitely high impedance, while most low-frequency circuits will stand a shunt of several megohms without altering their characteristic appreciably.

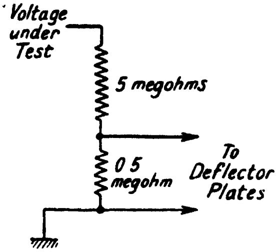
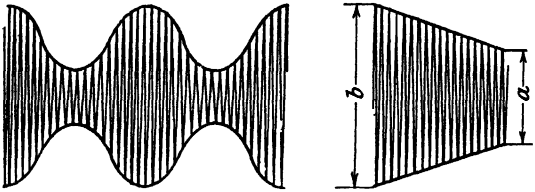


Fig. 12.3. Potentiometer for Reducing Proportion of Work Voltage Applied to Deflectors.

It is customary to connect the gun to earth. One deflector plate is then connected to the work or to the time base while the other is connected to a "shift" potentiometer which puts a small steady voltage on the plate. This enables the position of the trace to be moved about on the screen so that it can be centralised. Fig. 12.2 incorporates such a shift potentiometer.

Modulation Measurement. Waveforms can be examined at radio frequencies, although one is not usually interested in the exact waveform. A point of interest, however, is the measurement of modulation. This may quite simply be assessed by applying the radio-frequency voltage to the vertical deflector plates and adjusting the time base to operate at a frequency two or three times slower than the *modulation* frequency. This will result in the envelope of the modulated wave appearing on the screen rather in the form shown in Fig. 12.4 (*a*). The extent of the modulation can then be examined at will. With 100 per cent modulation, of course, the troughs of the modulation wave just touch the zero line.

Alternatively, one can apply the modulation frequency itself to the horizontal deflector plates in which case one obtains a figure of the form shown in Fig. 12.4 (*b*), and the ratio $\frac{b-a}{b+a}$ is the percentage modulation.



(*a*) (*b*)

Fig. 12.4. Traces obtained when Checking Modulation.

It is not even necessary to synchronise the time base. If the time base is allowed to operate at a random frequency a continuous hazy rectangle of light will appear with a brighter rectangle superposed in the central portion. This centre section will be well defined by two bright edges corresponding to the troughs of the waves shown in Fig. 12.4 (*a*) so that the distance *a* may be read off. The distance *b*, of course, is the full depth of the pattern.

Response Curves. Apart from the numerous applications of the cathode ray tube using time bases, there are various others, one of which is of particular interest to radio engineers. This is the use of the tube to plot response curves.

For this the voltage to be examined is applied to the vertical deflector plates in the usual way, but in this case we are not interested in the variation of the voltage with time but with frequency. Let us consider, for example, the response curve of an i.f. transformer. We know that actually the voltage is varying many hundreds of thousands times per second, but what we are interested in is the change of the r.m.s. value of this voltage as the frequency is altered.

Therefore, we have to arrange that the voltage applied to the vertical deflector plates is proportional to the r.m.s. value of the voltage, which we can do by using a valve voltmeter, replacing the ordinary meter with a resistance and applying to the deflector plates the voltage drop on this resistance. The deflection is then proportional to the input to the valve voltmeter, and if the voltage on the transformer increases so will the deflection of the cathode ray tube.

For the horizontal deflection we must now arrange some voltage which is proportional to the frequency. One simple way of doing this is to provide an oscillator with a two-part condenser. First part is the normal variable condenser which is adjusted to tune the circuit to the frequency required. The second part is a small trimmer condenser in parallel with the first condenser which causes the frequency to vary up and down by an amount corresponding to 10 or 20 kc/s. This trimmer is arranged to rotate continuously and is run by a small motor. On the same shaft is a variable resistance through which current is passed so that as the shaft rotates the voltage drop on the resistance increases and decreases at the same time as the frequency is varied.

The voltage on this resistance may be applied to the horizontal deflector plates, and this will cause the spot to move from side to side at a rate and an amplitude corresponding to the variation in frequency of the oscillator. Under these conditions the spot on the screen will trace out a response curve of the i.f. transformer or amplifier, as the case may be, and by adjusting the tuning of the i.f. circuits, it is possible to alter the shape of this response curve as required until it conforms to some predetermined form.

This method is used to considerable extent in works. It has the advantage of being very speedy and much more accurate than any attempt to adjust the response curve by use of a valve voltmeter. It is almost impossible to obtain the proper double hump response with any voltmeter method unless the somewhat cumbersome procedure outlined in Chapter VII is employed.

Alternative methods have been suggested for obtaining the variation on the horizontal deflector plates. For example, it is possible to use the variation of Miller effect in a valve. A valve with a resistive anode circuit will have a much greater input capacitance than normal due to the feed-back via the internal anode-grid capacitance. The extent of this reflected capacitance depends upon the amplification, so that if we can arrange to vary the amplification by some simple electrical means, we can automatically vary the input capacitance and this could be used to alter the frequency of the oscillator instead of the mechanically-rotated trimmer.

A vari-mu valve, therefore, is used, and the bias on the valve is varied by the application of a.c. voltage superposed on a steady bias. This causes the amplification to vary and with it the input capacitance, and hence the oscillator frequency, in unison with the mains voltage. All that is necessary, therefore, is to apply the mains voltage to the horizontal deflector plates and we once again obtain the necessary frequency scale.

The plotting of high-frequency response curves is not the only application of the tube in this manner. It is possible, for example, to plot a low-frequency response curve showing the variation of output with frequency over the whole of the audio range. In this case the frequency scale would be linked up, probably mechanically, with the control of a beat-frequency oscillator, and the vertical plates would record the variation in output voltage or, if desired, the voltage of any other part of the set.

The technique of frequency modulators is one requiring some care.

The reader who is interested is referred to *Cathode Ray Oscillographs* (Pitman) by the author, where the subject is treated exhaustively.

Valve Characteristics. One final application may be cited, that of the plotting of valve characteristics. If, for example, it is desired to trace out on the screen the variation of anode current of a valve with the grid voltage, one would set up the valve, apply a steady bias and superpose on this an alternating voltage of the required intensity to sweep the grid from zero to twice the grid bias. A corresponding alternating voltage applied to the horizontal deflector plates would elongate the spot in the horizontal direction as required.

For the vertical deflection one can insert a small resistance in the anode circuit of the valve and use the voltage developed across this resistance to deflect the spot in the vertical direction. This deflection would be proportional to the anode current of the valve and consequently the customary valve characteristic would be traced.

It would probably be found that the value of resistance necessary to give a satisfactory deflection would necessitate a resistance of too large a value. Several thousand ohms would probably be necessary, and this would affect the characteristic since the voltage on the anode would no longer be the full h.t. voltage due to the voltage drop on this resistance, and we should, in effect, obtain a dynamic characteristic. The remedy is, either to use quite a small resistance and apply this voltage to an amplifying valve, the output of which feeds the deflector plates on the tube, or alternatively, to insert a small coil in the anode circuit of the valve and mount this next to the tube in such a manner that it causes magnetic deflection of the spot for the vertical movement. The coil, of course, would be split in two parts so that it could be mounted symmetrically about the tube.

This brief summary will serve to show the increasing possibilities of cathode ray tube technique in set testing. For more detailed information the reader should refer to *The Cathode Ray Tube* by G. Parr (Chapman and Hall), and to *Cathode Ray Oscillographs* (Pitman), by the present author.

CHAPTER XIII

SOME CURIOUS FAULTS

IN previous chapters we have seen that method is an all important factor in tracing faults. Not only does this make the process more rapid, but it is a fascinating exercise for the brain to work on logical lines, for by a process of elimination we are bound to find the solution. Most of us enjoy detective fiction merely because exercising the mind in the tracing of clues is a pleasant occupation. If we learn to do this also in tracing wireless troubles, much of the tediousness will disappear.

Examples have already been quoted to illustrate the development of systematic testing, but it is not always an easy matter to interpret the results obtained, and the process has often to be extended to include several tests in succession.

The present chapter deals with some rather curious faults experienced in the course of routine work. The troubles may justly be termed curious, in that they were not discovered merely by conducting the simple tests already described, but required additional thought, guided by the clues obtained after making the normal measurements.

Grid Leak Troubles. An interesting case was that of a receiver which developed a curious hum. There was no simple reason for this trouble, since batteries were being used for both h.t. and l.t. supply. The quality of reproduction did not appear to suffer, but it was noticed that when going into oscillation the reaction was unusually smooth; even when the reaction condenser was suddenly increased the set slid into oscillation without any "plop." This effect supplied the clue, for reaction often becomes smoother as the grid leak increases in value. Tests showed that the grid leak (nominally 2 megohms) was actually 12 megohms, causing the grid circuit of the detector valve to pick up hum from the a.c. mains in the laboratory. Replacement with the correct value cured the trouble.

Partial Breakdowns. A curious fault developed in an amplifier resulting in a regular series of loud clicks, something like the ticking of a clock, but considerably faster. This, of course, is the effect often obtained with a broken grid circuit and the various stages were all examined for this defect, without avail. It seemed clear, however, that an intermittent discharge was taking place, so the various components were tested with a Megger in the hope of finding a leak from the terminals of a large fixed condenser to its metal casing or some such fault. The diagnosis was partly correct, for it was discovered that a low-frequency choke in the amplifier was short circuiting intermittently to frame. On replacing the choke the trouble entirely disappeared.

Misleading Measurements. One must always be sure, when testing a fault, that the very act of testing does not in its turn introduce misleading symptoms, or even partially cure the fault. An example of this occurred in a mains receiver. The last valve was taking no anode current, yet the valve itself was all right. This pointed to a break in the circuit, and after some investigation suspicion was centred on the self-bias resistance in the cathode circuit.

It might be argued that if the cathode resistance was broken no voltage would be developed across it. Yet a voltmeter connected across it registered 50 volts—about twice the proper value admittedly, but nevertheless, a voltage. The set was switched off and the resistance checked with an ohmmeter which showed a break as suspected. The explanation of the misleading voltmeter reading became obvious on further thought. The voltmeter itself had automatically completed the circuit, and the internal resistance of the voltmeter was acting as a cathode resistance. Hence the reading of 50 volts.

Switch Contacts. On another receiver a sudden fade would occur without any apparent reason. Signals would be quite normal and would suddenly fade away almost to nothing. Once again the process of elimination had to be brought into play, and it was found on replacing the coils in use with others of the simple plug-in type the trouble disappeared. The original coils were of the dual range pattern, having a self-contained switch, and it was found that one of the contacts of this was making a bad high-frequency joint, although it showed perfect continuity when tested with d.c. On opening the switch and reclosing it, so that the contact was made afresh, the trouble disappeared. A thorough cleaning of the contacts cleared the trouble.

Similar trouble was experienced in a receiver in which the switch was not self-contained, but mounted entirely separately from the coil. The switch, however, was of the same pattern as in the preceding instance, being one in which two springs were forced into contact. This form of switch is liable to give trouble at high frequency, the pressure contact not always being sufficient to give a good high-frequency joint.

Imperfect Assembly. The faults described so far have occurred in sets which were previously operating quite successfully. An unusual fault was once discovered in a hook-up on which experiments were being conducted. When the arrangement was completed, nothing whatever was received—not even the local stations. On inserting a milliammeter it was found that the first valve was not taking any current, yet an investigation of the circuit failed to reveal any obvious fault. The valve was replaced by another without making any difference to the results, and it was not until the step-by-step test with a voltmeter was carried out that there was found to be no connection between the anode terminal of the valve holder and the valve itself. Investigation showed that the holder was defective. In the process of assembly a small insulating washer had become inserted under the terminal nut of this contact on the valve holder, so insulating the terminal from the socket.

On another occasion a somewhat similar fault occurred in a coil. A special form of soldering tag was used, having two tags, one connected to the wire on the coil and the other to the external connection from the set. The tag was held under a terminal and an additional connection had been taken to this terminal. The circuit refused to function, giving every indication of a break, yet no break in any wire could be traced. The fault was finally located to the terminal itself. Firstly, the tag was held firmly by the two wires soldered to it. Secondly, the hole in the tag was a little larger than the stem of the terminal so that it did not make contact. Thirdly, the nut on the terminal was faulty, and did not screw right home on to the tag. These three effects conspired to give a complete break, between the terminal and the tag so that the wire connected to the terminal was not in contact with the other two (see Fig. 13.1).

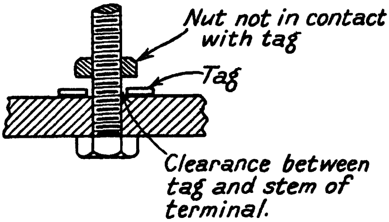

Nut not in contact with tag
Tag
Clearance between tag and stem of terminal.

Fig. 13.1. Illustrating a Curious Fault.

Tuning Faults. Two tuning faults may be cited as of interest. The first of these was both irritating and silly. The receiver under test used a gang-controlled circuit, the tuning condenser being of the completely screened type popular to-day. The circuits refused to tune properly, although a species of tune was obtained at one point of the scale. The coils were checked individually and proved O.K., and the condensers were not short-circuiting. After testing almost everything else the covers were removed from the condensers, when it was found that the spindle had jammed. The drive, which was of the disc type, was slipping on the spindle, so that the condensers were not rotating at all.

The second fault arose in testing a similar gang-controlled circuit in which a form of tuned-anode circuit was used. The r.f. condenser spindle was at earth potential, the h.t. point on the tuned-anode circuit being by-passed to earth by a condenser. The effective tuning capacitance was thus the tuning condenser in series with the h.t. by-pass condenser.

When the circuit was first tried it was quite satisfactory, but in a second test it was a mere shadow of its former self. After much searching it was found that the h.f. circuit was quite out of gang. It was then realised that the h.t. by-pass condenser was only ·001 μF, so that the maximum series capacitance was only 333 μF. On the original test the h.t. battery had a 2μF condenser across it external to the set, which put the circuits in gang, whereas on the second test this condenser had been omitted.

Pick-up Points. The attachment of a gramophone pick-up to a wireless set may sometimes give rise to trouble. If the inductance of the pick-up is high and the amplifier has a tendency towards instability, howling will occur when the pick-up is connected in circuit. The remedy is a leak across the pick-up of as high a value as will just give satisfactory stability. A more usual trouble is a howl or hum (particularly in a mains set) arising from the length of lead connecting the pick-up to the set. Most of us have, at one time or another, touched the grid of a detector valve with our fingers, and noted the resulting low-frequency howl, due to contact with an improperly earthed body of considerable dimensions. A long lead can cause similar effects. If, however, it is necessary to use a long lead, the trouble may be generally overcome by using lead-covered wire and earthing the lead covering.

When a gramophone pick-up is attached to a set through a suitable transformer, the grid circuit is apt to become noisy since it is in close proximity to the iron core of the transformer. This trouble may be often entirely overcome by connecting the filament side of the secondary to one side of the primary (and if necessary to the core also).

Poor Quality. Another peculiar fault occurred in a battery-driven set. For months the set had been giving excellent quality of reproduction, when suddenly bad distortion started for no apparent reason. The valves were found to be all right, the h.t. and grid bias battery showed full voltage, and the l.t. accumulator had just been charged.

When re-checking the l.t. voltage on the set, however, it was noticed that a reversed reading was obtained. Yet the accumulator was apparently correctly connected. A further investigation showed that the polarity of the accumulator had been reversed and on connecting it up the other way round the quality at once became normal. Needless to say the accumulator was not left in this condition but was returned poste-haste to the charging station.

During a test on a powerful mains receiver some trouble was caused by a curious hum which would occur at intervals and then entirely disappear. The h.t., l.t. and grid bias potentials were all checked and found correct, whilst there was no apparent loose contact. Following the methods already outlined for testing a set, various stages were eliminated in order to discover in which portion the hum was occurring. This was done by connecting a 2 microfarad condenser from grid to filament, starting with the last valve and working back to the first stage. By a mistake the condenser was connected between the grid of the detector valve and the H.T.+. It charged with the usual spark, and the set immediately became dead silent. An adjustment of the dials brought in the usual stations, but without a trace of hum! Undoubtedly the charging of the condenser had cured the trouble. A careful examination of the grid circuit brought to light a bad contact in one of the leads. The current surge when charging the condenser had momentarily welded the loose contact together. Remaking this contact effected a permanent cure.

Another source of bad quality is a broken diode resistance. The diode then has an a.c. load via the coupling condenser and grid leak of the following a.f. stage, but it has no d.c. load, and from the discussion of diode detectors in Chapter VI it will be clear that serious distortion will result. The point is that the circuit will still work and will not fail to function altogether as might at first be assumed.

Another cause of distortion and hum is a short circuit between heater and cathode of the output valve. This does not develop, as a rule, until the set has been switched on for some time. In effect it places an a.c. potential across the cathode-bias resistor which causes hum (though not as much as might be thought because the output stage will tolerate quite large hum voltages) while it also throws the effective bias wrong, causing distortion.

Saturation. Some time ago I was asked to inspect a set built to standard design. In switching on the set, the quality of reproduction from the loud speaker was excellent for the first two minutes, after which there appeared a low hum and a "cutting up" of speech and music, entirely spoiling the reproduction. The set was examined carefully to see whether any parts were overheating and the valves were replaced one by one. Still the trouble continued. The output choke, however, had rather a smaller iron circuit than one would recommend for use with a high value of anode current, and it was decided that this might be a possible cause of trouble. On replacing it with another more suitable type the trouble completely disappeared. The most interesting feature of this fault was the gradual appearance of distortion, due to an apparent slow tiring of the iron.

On another occasion a similar effect was observed in a mains set, but this time it arose from a totally different cause. The symptoms were as before, hum and distortion gradually building up after the set had been in use for several minutes. There could be no question of saturation in this case, since the chokes used were quite adequate. The fault was discovered by systematic tests with the voltmeter. As soon as the set developed distortion it was found that the grid bias on one of the low-frequency valves had risen to an unsuitably high value, indicating that the cathode resistance for that particular valve had momentarily increased considerably. A test across the resistance gave a reading of several megohms, yet as soon as the set was allowed to cool the resistance assumed its normal value. The trouble here was caused by the expansion of the former on which the resistance had been wound, causing a break in the wire.

When the former was allowed to cool the broken ends of the wire came together again.

Squealing. A very puzzling fault once occurred in a very simple receiver consisting of a detector followed by two a.f. stages. In order to keep the cost low, the receiver had not been thoroughly de-coupled, but it was sufficiently stable for all normal purposes. On building a duplicate set it was found that a high-pitched squeal had developed, and as it was not desired to depart from the original circuit, every effort was made to locate the cause.

Every component was replaced without success until it was noticed that the very act of removing the grid condenser from the baseboard, *without disconnecting it*, cured the trouble. Following this up, it was noticed that the baseboard had been lightly stained, whereas the original baseboard was plain. Replacing the baseboard cured the whole trouble. Investigation showed that the stain used was semi-conducting and allowed high-frequency eddy currents to be set up in the baseboard itself.

This fault serves to emphasise the golden rule of fault-finding—never take anything for granted.

Parasitic Oscillations. A difficulty which is occasionally experienced is that of an oscillation at some frequency other than that being received. A valve circuit having a centre-tapped coil in both grid and anode circuits will often oscillate at a frequency determined by one half of each coil tuned by its own self-capacitance. The symptoms are that the circuit goes into oscillation, usually with a click in the loud speaker, but such oscillation does not heterodyne with the incoming signals, and is unaffected by alteration of the tuning. All the usual tests show that the circuit is in an oscillating condition, and the trouble is sometimes difficult to locate.

A troublesome oscillation of this sort was once experienced with a dual-range coil in which the grid was connected to a centre-tap on the short-wave section. The arrangement behaved satisfactorily on the medium waves, but on long waves the reaction produced a parasitic oscillation instead of the true one. Altering the tap to the top of the coil overcame the trouble, but this was begging the question, and a cure was finally obtained by inserting a resistance of 100 ohms in series with the reaction winding.

This latter method is often useful, since parasitic oscillations nearly always occur at a higher frequency than that being received. Therefore, by a suitably placed resistance or choke of the right value the circuit can be made to damp out the parasitic oscillation without seriously affecting voltages of the correct frequency. The problem, however, is one of design rather than ordinary fault-finding.

Jumping to Conclusions. The final fault to which reference may be made is an interesting commentary on the statements made elsewhere in this book, regarding the practice of diagnosing a fault from the noise the set makes. While in many simple cases the experienced operator can tell what the defect is from the noise which the set makes when it is switched on, sooner or later such crude methods are bound to fail, and therefore I have not stressed this aspect of the question.

The reliance I place, myself, upon such methods is limited to a few isolated cases which have already been mentioned, such as the distinctive choked sound produced by a broken grid circuit. Even such simple indications are by no means infallible as the following example will show.

The fault in question developed on a three-valve amplifier, which was being tested on the bench. It gave quite good results at first, but after one or two alterations had been made it suddenly developed the curious strangled effect usually associated with a broken grid circuit. Seeing that the apparatus was merely hooked up, I considered the possibility of a broken grid circuit quite feasible, and went over all the connections very carefully. No success attended these efforts, and the difficulty still remained.

Feeling rather irritated (because all this, of course, was wasting time, since until the fault was found I could not proceed with what I wished to do), I resorted to elimination, and gradually found that the trouble still occurred even with the last valve only in circuit. I therefore spent some considerable time chasing round the grid circuit of the last valve looking for some obscure fault such as a badly assembled terminal or something of this nature.

Finally I did what should have been done at the start, applied voltmeter tests, and found that the valve was functioning quite satisfactorily. The whole trouble was that I was using a choke output circuit, and the condenser feeding the signal current on to the loud speaker had broken down. Yet the symptoms were such that I was almost certain of a broken grid circuit, and wasted considerable time trying to find a fault which was not there.

APPENDIX I

TIME CONSTANT

THE term "time constant" is frequently encountered in radio practice. It is an expression mainly used in connection with the charging and discharging of condensers. If a condenser is connected through a resistance to a battery or other source of voltage the current flowing depends on the difference between the applied voltage and the "back e.m.f." of the condenser. At first, when the condenser is uncharged, the full voltage is operative so that the current is a maximum, limited only by the resistance, but as the condenser charges up (and hence acquires some voltage), the effective potential difference falls off.

Hence the charging current falls and the rate at which the charge builds up will decrease progressively. Indeed the rate of charge is inversely proportional to the amount of charge already acquired at any instant, and theoretically the condenser never becomes fully charged.

A phenomenon of this sort, in which the effect is proportional to itself, obeys a law involving a constant ε, an often-found constant in physics, used as the base of the earliest form of logarithms, and having a value of approximately 2·7183.

The voltage on a condenser of capacitance C charged from a battery V through a resistance R is given by

$$v = V\left(1 - \frac{1}{\varepsilon^{t/CR}}\right)$$

where t is the time after switching on. If $t = CR$, this becomes $v = V(1 - 1/\varepsilon) = 0{\cdot}63\,V$ approximately, i.e. the condenser reaches 63 per cent of its full charge in a time equal to CR, and this is called the *time constant* of the circuit.

The voltage growth, in terms of the time constant, is as shown below:

Time . . .	0	CR	$2CR$	$3CR$	$5CR$
Percentage of full voltage (charge) . .	0	63	86·5	95	99·3
Ditto (discharge) .	100	37	13·5	5	0·7

We are often more interested in the manner in which a condenser will discharge through a resistance. Here the same law applies, the discharge current being proportional to the amount of charge left in the condenser, so that it grows less and less and theoretically the condenser never completely discharges.

The voltage on a condenser C discharging through a resistance R is given by

$$v = V_o / \varepsilon^{t/CR}$$

In a time $t = CR$ the condenser will have discharged by 63 per cent, so that its voltage will be 37 per cent of the initial voltage, and so on, as shown in the table above.

Quite often, however, we wish a condenser to hold its charge for a reasonable time, and we have to design our circuit such that the loss of charge in a given time is small. We do this by making the time constant large, either by making C or R large, according to the conditions.

Calculations here can be worked out from the expression given, but when t is small compared with CR the loss of voltage is very nearly linear. The condenser will lose just over 10 per cent of its voltage in a time $t = 0{\cdot}1\ CR$, and for any smaller time it will be proportionally less.

Thus, if we want a condenser not to lose more than 1 per cent of its voltage we must make $t = 0{\cdot}01\ CR$. If $t = 0{\cdot}01$ second, $CR = 1$. Hence if $C = 1\ \mu$F, R must be 1 megohm, or if $C = 0{\cdot}1\ \mu$F, R must be 10 megohms.

C and R are in farads and ohms, but since we are dealing with the product we can express C in μF and R in megohms, which is more convenient.

A similar exponential law applies to the growth and decay of a circuit containing inductance. The time constant here is L/R, so that when switching on an inductive circuit the current will attain 63 per cent of its full value in a time equal to L/R, and will not be tolerably steady until after about five times this period. The inductive time constant, however, comes into play much less often in set testing technique.

APPENDIX II

RESISTANCE-CONDENSER NETWORKS

THE resistance-coupled circuit of Fig. II.1 is often encountered, and a simple analysis of its operation is useful. Voltage is developed by the valve V_1 across R. This in turn passes current through the circuit CR_1 (neglecting for the moment the network R_2C_g).

At middle frequencies the reactance of C is very small compared with R_1 and the full voltage is developed across R_1. At low frequencies this no longer holds good and appreciable voltage is lost on C.

The current through CR_1 is $e/\sqrt{R_1^2+(1/\omega C)^2}$, and the voltage across R_1 is

$$\frac{e\,R_1}{\sqrt{R_1^2+(1/\omega C)^2}} = \frac{R_1C\omega}{\sqrt{1+(R_1C\omega)^2}}\,.\,e.$$

This may be evaluated for any given conditions. Alternatively, if the voltage across R_1 is to be 90 per cent of the full amount the expression must be equal to $0{\cdot}9e$, whence $R_1C\omega = 2$ approximately.

This is a convenient criterion to memorise. If $\omega = 315$ (50 cycles) the product $R_1C = 0{\cdot}0065$ and since R_1 is usually known this specifies C at once.

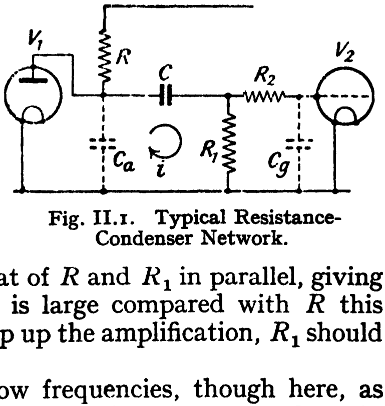


Fig. II.1. Typical Resistance-Condenser Network.

The gain obtained from V_1 is determined by the effective impedance of the whole network. At middle frequencies this is simply that of R and R_1 in parallel, giving a gain of $\mu v_g RR_1/(R+R_1)$. If R_1 is large compared with R this becomes simply $\mu v_g R$, so that to keep up the amplification, R_1 should be several times as great as R.

The same conditions apply at low frequencies, though here, as just shown, the full voltage is not transferred to the next valve. At high frequencies the reactance of the capacitances C_a and C_g (including stray circuit capacitances) becomes comparable with R, and the effective amplification begins to fall off with increasing rapidity.

C_a and C_g may be considered as operating together and if C_g represents the total shunt capacitance (including stray circuit capacitance) the amplification becomes $\mu v_g\,.\,R/\sqrt{1+R^2C_o^2\omega^2}$, assuming that R_1 is sufficiently large to exercise negligible shunting of R. If not, for R write $RR_1/(R+R_1)$.

We can evaluate the expression for varying degrees of loss and we find that for a loss of just over 10 per cent $RC_o\omega = 0{\cdot}5$, another convenient figure. If R=100,000 ohms and C_o=30 μμF this expression shows that the amplification will start to fall off at around 25,000 cycles/sec.

Grid Stoppers. The network R_2C_g constitutes a grid stopper and is sometimes used to limit the amplification at high frequencies. The voltage across R_1 is divided across R_2 and C_g in proportion to the resistance R_2 relative to the reactance of C_g. The latter falls off rapidly with increasing frequency so that at radio frequencies it may be negligibly small, resulting in all the voltage being lost on R_2. Thus any radio-frequency currents present will be cut off practically completely.

The action is the inverse of that which occurs with that coupling condenser C in conjunction with R_1 and the device can be quite effective provided R_2 is not so large as to cause appreciable loss at the upper audio frequencies. By similar reasoning to that previously adopted it is easy to show that the proportion of voltage actually developed across V_2 is $1 / \sqrt{1+(R_2C_g\omega)^2}$.

If $R_2C_g\omega=0{\cdot}33$ approximately 5 per cent of the voltage will be lost, so that if ω is chosen to correspond with the highest audio frequency required, R_2 can be calculated if C_g is known. C_g ranges from about 15 μμF for a pentode output valve up to 100 μμF or even more for a triode, the greater figure in the latter case being due to the marked Miller effect which is obtained.

With conditions chosen to suit this criterion the voltage developed by a frequency 100 times as great will be only 3 per cent of the full amount.

APPENDIX III

NEGATIVE FEEDBACK

IF a fraction of the output voltage from an amplifier is fed back to the input in such a direction as to oppose the signal already existing there the effective gain of the amplifier will be reduced, but the response will be improved because at frequencies where the amplifier gain is greater than normal the feedback will also be greater, and *vice versa,* so that a levelling of the response is obtained.

If v is the input voltage and A is the amplifier gain, then the output voltage will be Av. Let us feed back a small proportion of this—βAv—back to the input. This will reduce the output, and if we wish to restore it we must increase the input voltage by a corresponding amount. Hence to obtain an output of Av we need an input of $v+\beta Av$.

The effective gain is thus $Av/(v+\beta Av)=\frac{A}{1+\beta A}$. If βA is large compared with unity, this expression becomes simply $1/\beta$. In other words the gain is solely dependent on the feedback factor and is not dependent on the gain of the amplifier as such. Hence changes in valves, h.t. supply or even component values will not alter the gain, nor will changes in the value of the circuit constants with frequency, so that we have an amplifier which is uniform in performance and exceptionally stable—an ideal arrangement for measurement.

These ideal results are obtainable in practice within the limits which keep βA large compared with unity. At each end of the frequency range a point is reached where the normal amplification falls off rapidly, and here the feedback conditions are not complied with.

A simple example will serve to illustrate the conditions. Assume an amplifier with a gain of 2,000. We must make βA at least 10, so that $\beta=1/200$. The effective gain is thus 200 so that we have sacrificed overall gain to obtain performance. If we still need a gain of 2,000 we must make A larger—say 20,000, which will enable us to reduce β to $1/2000$.

The manner in which the voltage is fed back varies with circumstances. Usually voltage is fed from the last anode through a suitable resistance to a resistance in the cathode or grid circuit of the first valve, the arrangement being so chosen as to provide the correct direction of feedback, and the resistances being so designed that the proportion of the voltage actually injected into the first grid circuit is β times that at the output.

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